

**AN ENVIRONMENTAL EVALUATION OF
THE EFFECTS OF THE ELDOR MINES
RABBIT LAKE OPERATIONS ON
WOLLASTON LAKE**

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TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	1.1
2.0 WATER QUALITY CRITERIA AND THE BASIS FOR THEIR SELECTION	2.1
2.1 Water Quality Criteria for Radionuclides	2.2
2.2 Water Quality Criteria for Trace Elements	2.5
2.2.1 Uranium	2.5
2.2.2 Arsenic	2.7
2.2.3 Copper	2.9
2.2.4 Lead	2.10
2.2.5 Nickel	2.12
2.2.6 Selenium	2.13
2.2.7 Vanadium	2.15
2.2.8 Zinc	2.17
3.0 SUMMARY OF ENVIRONMENTAL MONITORING DATA	3.1
3.1 Water Quality	3.2
3.2 Sediment Quality	3.6
3.3 Fish Tissue Analyses	3.7
4.0 SIGNIFICANCE OF MONITORING RESULTS	4.1
4.1 Effects on the Aquatic Environment	4.1
4.1.1 Dilution in Hidden Bay and Wollaston Lake	4.1
4.1.2 Radiation Effects on Aquatic Environment	4.3
4.1.3 Chemical Effects on Aquatic Environment	4.4
4.2 Effects on Local Human Populations	4.4
4.2.1 Assessment of Chemical Effects	4.5
4.2.2 Assessment of Radiological Risk	4.6

	<u>Page</u>
5.0 CONCLUSIONS	5.1
6.0 RECOMMENDATIONS	6.1
7.0 REFERENCES	7.1

APPENDIX 1: Dose Rates to Aquatic Biota

1.0 INTRODUCTION

In 1968, Gulf Minerals Canada Ltd. discovered uranium mineralization around a small body of water referred to by the original exploration geologists as Rabbit Lake. Subsequent drilling at the site discovered sufficient uranium to justify development, and three companies (Gulf Minerals Canada Ltd., Gulf Oil Canada Ltd. and Uranerz Canada Limited) proceeded with development as partners. Gulf Minerals became the operating partner and began construction of a mining and milling operation in 1972. By 1974, the mining and milling processes were in operation and routine monitoring of the release of mining and milling effluents to Wollaston Lake began. Regular monitoring under the supervision of both the Saskatchewan and Federal Governments has been carried out since that time. In 1981, Eldor Resources became the operator and, since that time, has been responsible for operations and environmental management of the operation.

Collins, Pow and Hidden Bays of Wollaston Lake are adjacent to the Eldor Resources uranium mining operations and the latter two have received drainage and treated process waters. The Umpherville River drains Chenakow Lake and its surrounding watershed and discharges with a mean annual flow of about $6 \text{ m}^3/\text{s}$ into Hidden Bay. This river is unaffected by any uranium mining and milling operations, and is considered for the purposes of this study as a good control watershed. In addition to the Umpherville River, 13 other smaller streams of various sizes enter Hidden Bay. Of these, two, the small stream draining Park's Lake is affected, to a small degree, by the Eldor Resources mining operation, while the second stream draining the tailings management area is affected to a significant degree by the facility.

Collins Creek drains a watershed to the west of Wollaston Lake which incorporates Lampin and Kewen Lakes and empties into Collins Bay with a mean annual discharge of about $5 \text{ m}^3/\text{s}$. Exploration and development activities in Collins Creek watershed have been occurring over the past several years making analysis of this watershed unsuitable as a 'background' reference location, although the water quality data from this area suggest no significant deviation from background has occurred. In addition to Collins Creek, seven small unnamed streams flow into Collins Bay from the northwest. These streams would not be expected to be affected by any aspect of current mining and milling operations. The development of the open pit deposit on the edge of Collins Bay is taking place at an elevation below that of the bay and all water flow is through

groundwater seepage from the bay into the pit. Water from the pit in Collins Bay is then pumped to the mill water treatment facility prior to its subsequent monitoring and discharge to Hidden Bay. Because no waters from the operation enter Collins Bay, this portion of Wollaston Lake has not been investigated in detail as a part of this study.

Pow Bay is a small bay located between Hidden Bay and Collins Bay. Up until 1977, this bay received mine water drainage via upper and lower Link Lake and Rabbit Creek. This bay in the past may have been expected to show the influences of mine water discharges. At present, cooling waters and drainage waters from portions of the waste rock area enter Pow Bay via the link lakes. Eldor Resources is, at present, preparing a detailed evaluation of the significance of the inputs of potential contaminants to the Pow Bay watershed and decommissioning recommendations for the area to ensure no unacceptable long-term effects occur.

With the exception of those discharges to the Pow Bay watershed, virtually all of the mine water, process water and site runoff that may be potentially contaminated by the mining and milling operation is discharged after treatment and routine monitoring to Hidden Bay. Hidden Bay is also the location of Hidden Bay Lodge which is the closest permanent population to the mine site. For these two reasons, data from Hidden Bay were reviewed in detail and the majority of the conclusions and recommendations focus on this area (Figure 1). Both monitoring data and present and future site plans would suggest that if any environmental concerns were to arise related to water discharges, Hidden Bay would be the first area in which they would become apparent.

In preparing the data for analysis in this study, it was necessary to reduce large amounts of individual monitoring data which was often expressed in different ways and which often had various degrees of uncertainty associated with it. When monitoring values appeared which were either very low or very high as compared with other data collected from the same area, they were identified as outliers and not included in the analysis. In many cases, the presence of outliers could be traced to incorrect units or faulty analyses. In cases where a reason for the outlier could not be identified, its significance from an environmental perspective was evaluated and recommendations for cross-checking made.

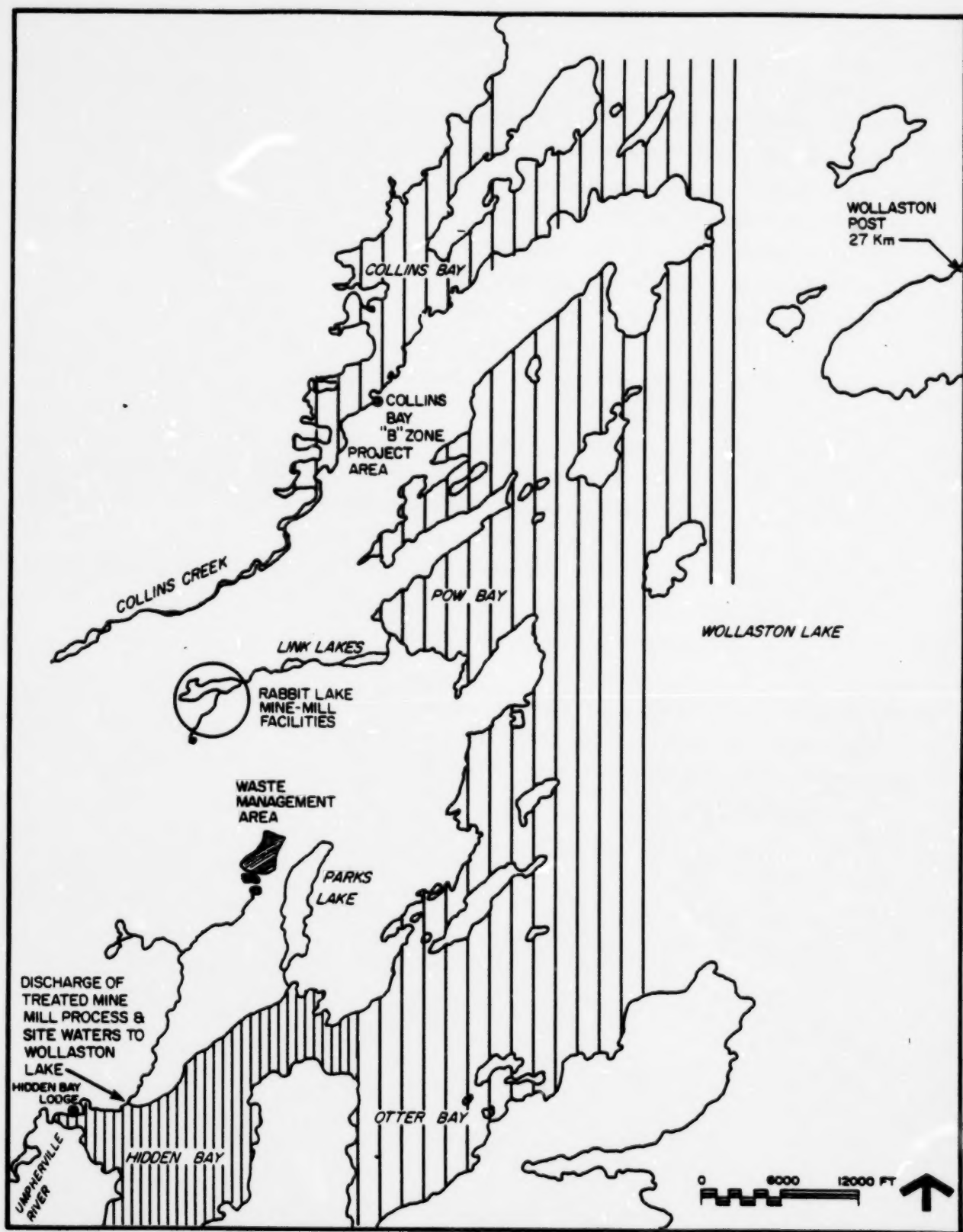
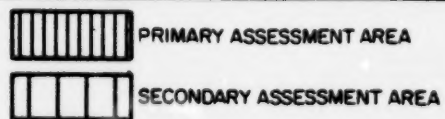


FIGURE 1 STUDY AREA
ASSESSMENT OF DISCHARGES
FROM ELDOR MINE & MILL



Summary tables of data have been produced in order to show data and from which to select absolute values for evaluation of environmental and human health significance. Where possible, the environmental significance of the water quality parameters have been expressed on a common basis in order that the significance of radionuclides such as radium can be compared with the significance of stable elements such as arsenic. Much of the data appearing in the summary tables have been rounded to one significant figure to reflect the uncertainty in the analytical data.

The studies which have been reviewed in compiling this assessment include:

- o the annual reports of environmental monitoring data produced by Gulf Minerals and more recently Eldor Resources as the operators of the site;
- o routine monitoring studies carried out by Saskatchewan Environment as part of their province-wide monitoring program; and
- o special studies carried out on the site by Gulf Minerals, Eldor Resources, Saskatchewan Research Council, National Uranium Tailings Program, Environment Canada and several private consulting companies.

In general, the vast majority of data collected, analyzed and reported by these various organizations is internally consistent, and no environmentally significant differences were found that could not be directly traced to reporting inconsistencies or differences in analytical methodology.

2.0 WATER QUALITY CRITERIA AND THE BASIS FOR THEIR SELECTION

Water quality criteria are composed of both standards and objectives. Standards are set by regulatory agencies such that, if a water body meets all applicable standards, that water is judged to be safe for all of the uses for which the standards were set. Water quality objectives are set as levels which are considered to be optimum for all uses of man and natural biota such as fish. Water quality objectives are usually more strict or set at lower concentrations than standards and, as such, incorporate a 'safety factor' into them relative to the standards. It is important to note that a lower level of a chemical in water does not necessarily denote a better or safer water. For example, it has recently been shown that low levels of calcium in water can lead to increased risks of heart attacks. For trace elements in the water that are essential to life, there is an optimum level around which objectives should be set.

Water quality criteria (standards and objectives) for radionuclides in water are set in order to ensure that any member of the public who fishes, drinks, swims or otherwise uses the water is not exposed to a risk any greater than a small fraction of which he would be exposed to in everyday living. This ensures that the group which is most likely to come in contact with radionuclides is adequately protected, and that everyone else who may come in contact with radionuclides less frequently is more than adequately protected.

Water quality criteria for trace elements that are non-radioactive are set based upon concentrations which have been shown to be present in natural waters and not to cause any detectable deterioration in natural populations or health effects. For many trace elements, laboratory tests of their toxicity have been carried out and criteria set which incorporate a safety factor usually of on the order of 10 to 100 to ensure that the most sensitive part of the natural system is not affected.

For some radioactive elements, such as uranium, water quality criteria are set based upon its chemical toxicity and not its radiotoxicity. For other elements, such as arsenic, water quality criteria have been evaluated both on the basis of its chemical toxicity with the application of an appropriate safety factor and on the basis of its risk of contributing to cancer as is done for radionuclides. For example, the maximum acceptable level of arsenic in public drinking waters is currently set at 0.05 mg/L and is a level at which no

specific illnesses have been observed to occur. Arsenic is also known to be, like radionuclides, a cancer-causing substance and ingestion of arsenic in water and food, like the ingestion of radionuclides in water and food, are suspected of resulting in a risk of developing cancer. In the case of arsenic, the current limit of 0.05 mg/L in water is expected to result in a cancer risk of 10^{-2} or 1 in 100. The corresponding risk (10^{-2}) for radium-226 in drinking water would correspond to a level of about 26 Bq/L (700 pCi/L). Thus, the maximum level of radium-226 in drinking water of 10 pCi/L incorporates a safety factor of about 70 times greater than that for arsenic. These facts, however, are further complicated by the fact that arsenic has been shown to be an essential trace element in some animal species.

This study does not go into the reasons why there are greater safety factors built into water quality criteria for some trace elements or radionuclides than others. In general, however, experience has shown that once a standard is set, it is very seldom increased even if subsequent research shows that the safety factor that is built in is outside of the generally accepted 10 to 100 range accepted for most trace elements. Thus, historic and reasons of general public concern have resulted in the standards for radionuclides incorporating in them 10 to 100 times more of a safety factor than for non-radioactive trace elements.

The following sections provide a discussion of water quality criteria for the radionuclides and trace elements of concern that are released from the Rabbit Lake facility.

2.1 Water Quality Criteria for Radionuclides

Water quality standards for radionuclides, with the exception of uranium, are set in order to ensure that the risk of developing a disease because of exposure is very low. The maximum allowable exposure to all man-produced radiations for members of the general public has been set in Canada by the Atomic Energy Control Board at 5 millisieverts per year (5 mSv/a). If members of the general public was exposed to this level of radiation, they would have about a 1 in 10,000 chance of dying of a cancer caused by this exposure sometime in the future. Natural background radiation in areas such as Wollaston Lake is close to 2 mSv/a. This means the maximum allowable exposure is set at about two and one-half times natural background levels of exposure to natural radiation in this area, and the risk associated with this exposure is less than that to which most people are exposed to in their everyday working life.

The principal route of exposure to radionuclides from the Rabbit Lake facility in the Wollaston Lake area is expected to occur from drinking water and eating fish in the area. In assessing the risk to individuals in the Wollaston Lake area for the purposes of this report, we have assumed that the individual most at risk would be someone who were to live on Hidden Bay year-round and drink 600 L of water from the bay and eat 20 kg of fish per year from the bay. The 1984 feasibility study on the decommissioning of the Rabbit Lake tailings estimates that this person would receive about 100 times more exposure from the Rabbit Lake facility than the average person living in Wollaston Post. Thus, if conditions are safe for the person living on Hidden Bay year-round, which receives all of the water discharges from the Rabbit Lake operation, they will be that much safer for residents of Wollaston Post.

The water quality objectives for radionuclides were set initially in order to ensure that individuals who drank water and ate fish from waters containing radionuclides were adequately protected from any significant radiation risk. Over the past decade, newer research data have resulted in the changing of ideas about how much radionuclides are concentrated in food chain organisms, how much of a particular radionuclide might be taken up into the body by someone ingesting food containing the radionuclide, what radiation dose is received from this uptake and what is the danger or risk from a particular radiation dose. This research has changed the resultant level of exposure to radionuclides that is deemed to be acceptable. In instances where new research has indicated much less of a risk than was initially expected, there has been a reluctance to increase the water quality objective. In other instances, if a particular radionuclide was found to be of a greater risk but still at a safe level, then no change would necessarily be made. In other cases, if a chemical risk from a radionuclide was found to be greater than that posed by the radiation risk, then the more stringent chemical standard would be used.

Table 2.1 presents a comparison of the radiological dose associated with drinking water and consuming fish from a given body of water meeting surface water quality objectives and from Hidden Bay in particular. The first column presents the radionuclide considered. The second column is the bioconcentration factor used in the calculation of the amount of a given radionuclide that may be found in a fish harvested from that water. Presented along with the literature value is an observed range in Hidden Bay. These values are in general agreement with the values observed from Hidden Bay

TABLE 2.1: RADIOLOGICAL DOSE COMPARISON FOR URANIUM DECAY SERIES RADIONUCLIDES

Radionuclide	Bioconcentration Factor in Fish Assumed Literature Observed	Fractional Uptake Assumed	Dose Conversion Factor Used D ₅₀ Sv/Bq	Water Concentration Calculated to Give a Dose Equivalent of 50 mSv/a ^a Assuming Higher Bioconcentration Factor	Water Quality Objective	Safety Factor	Observed Value in Hidden Bay	Safety Factor in Hidden Bay	
Uranium (U-238, U-234)	10	2-10	0.05	1x10 ⁻⁶	62.4 Bq/L or 3 mg/L	20 ug/L	120	3 ug/L	800 ^a
Thorium-230	30	10-30	0.03 0.0002	5.2x10 ⁻⁶ fish 3.5x10 ⁻⁶ water	0.15 Bq/L	1.1 Bq/L	0.14	L 0.01 Bq/L	GT 15
Radium-226	20	10	0.2	6.8x10 ⁻⁶	7.4 Bq/L	0.11 Bq/L	67	0.007 Bq/L	1,060
Lead-210	50	20	0.2	2.1x10 ⁻⁵	1.5 Bq/L	0.62 Bq/L	2.4	L 0.02 Bq/L	GT 75
Polonium-210	50	20	0.1	5.3x10 ⁻⁷ ^a	9.4 Bq/L ^a	NA	NA	L 0.02 (est.) Bq/L	GT 470

* Dose calculated for a person consuming 600 L of water and 20 kg of fish per year.

GT = greater than.

** Uranium safety factor based only on radiological considerations.

*** In the case of Po-210, the non-stochastic dose is limiting and an H₅₀ dose conversion used.

although generally lower than literature values. In calculating the data in Table 2.1, the higher literature values were used. This has the effect of underestimating the actual safety factor present. For example, the bioconcentration factor for uranium is given as ten. This means a fish living in water which contains 1 mg/L or 1 mg of uranium/kg of water would have a concentration of 10 mg/kg in its flesh. The third column is the fractional uptake of the particular radionuclide from food or water into the body. In the case of thorium, two values are presented. The first uptake value of 0.03 or 3% would apply to organic forms of thorium such as may be found in fish tissue and which would be more readily digested and adsorbed into the body. The second value applies to inorganic thorium such as may be found in drinking water. This form of thorium is not as readily digested and an uptake of 0.0002 or 0.02% was used for thorium in water. For the other radionuclides, the same value is used for both water and fish.

The dose conversion factor used is from Johnston and Dunford (1983) and is used to convert the quantity of radionuclide ingested into a non-stochastic dose to the most sensitive tissue expressed in sieverts per year. The non-stochastic dose is limiting for all radionuclides except polonium-210. In this instance, the stochastic dose was calculated.

The fourth column on Table 2.1 is the maximum concentration of each radionuclide released from Rabbit Lake that would be allowed from a radiological perspective in a given body of water from which any person is likely to consume 600 L of water and 20 kg of fish per year. The next column presents the water quality criteria as they presently exist. Based upon a comparison of the safety factor which exists for the radionuclides, it is apparent that criteria for several radionuclides are more strict than for others. For comparative purposes, the values that are actually observed in Hidden Bay and the resultant radiological safety factor are also presented. A review of these data show that the levels of radionuclides which have been monitored in Hidden Bay water and fish are such that it is safe to both obtain all of ones drinking water and fish from Hidden Bay.

Uranium is considered to be more dangerous from a chemical standpoint than from its radioactivity. Accordingly, the 'safe' level for uranium or the maximum level permissible in drinking water is, based upon radiological considerations, 2,400 ug/L, with the objective based upon chemical considerations being 20 ug/L.

The safety factor of 800 shown for Hidden Bay is based upon radiological considerations. The safety factor based upon chemical considerations would be on the order of ten times.

2.2 Water Quality Criteria for Trace Elements

In addition to radionuclides, uranium mining and milling facilities release small amounts of trace elements that are not radioactive into the waters of nearby lakes and rivers. All of these trace elements, like the radionuclides, are found naturally in the water, and it is only when their concentrations rise above a certain level is a risk to man and the natural environment presented. The following sections present a discussion of the basis on which standards are set for each of the trace elements about which concern has been expressed at the Rabbit Lake mine. Uranium is considered in this context as a trace element because it is more of a chemical hazard than a radioactive risk.

2.2.1 Uranium

Uranium consists of three natural isotopes, primarily U^{238} (99.27 atom %), with U^{234} (0.00572 %) and U^{235} (0.72%) also represented. All three isotopes are unstable, emitting primarily alpha and also gamma radiation as they decay. U^{234} decays most rapidly with a half-life of 2.48×10^5 years. It is replenished by the slower decay of U^{238} with a half-life of 4.5×10^9 years. Natural uranium is typically near secular equilibrium, with these two isotopes contributing almost equally to its radioactivity. Regulatory objectives for uranium are based on chemical rather than radiological effects on man and other animals. Chemical properties do not vary among isotopes.

Environment Canada (1983) reported typical natural uranium concentrations of 1-5 mg/kg in sandstones and 2-5 mg/kg in limestones. Concentrations in the clay fraction of glacial tills are typically 1-7 mg/kg (NRCC, 1983). Commercial ore deposits range from 0.1-60% uranium.

Environment Canada (1983) reported uranium concentrations in Rocky Mountain streams ranging from 0.02 to 89.8 ug/L (median 0.1 ug/L) and in Canadian Shield lakes ranging from 0.001 to 170.0 ug/L (median 0.05 ug/L). Stream sediments ranged from 0.1 to 430 mg/kg (median 3.4 ug/kg) while lake sediments ranged from 0.1 to 733 mg/kg

(median 4.6 ug/kg). Uranium is typically found in the sediments of northern Saskatchewan lakes at levels ranging between 10 and 100 mg/kg dry sediment.

Toxic effects of uranium on aquatic biota vary with species and water hardness. The concentrations required to kill 50% of fish in 96 hours (LC50) ranges from 2.8 mg/L (fathead minnows, Targwell and Henderson, 1950) to 8.0 mg/L (brook trout, Davies, 1980) in soft water. In hard water, equivalent mortality of fathead minnows occurs at 135 mg/L. Bringmann and Kuhn (1959) in Environment Canada, 1983 reported incipient lethal effects of uranium at 13 mg/L in the cladoceran, Daphnia, 22 mg/L in the alga, Scenedesmus, and 28 mg/L in the protozoan, Microregma. Environment Canada (1983) recommended that 0.30 mg/L should be considered an acceptable uranium concentration for protection of aquatic life, based on application of a 20-fold safety factor to the rainbow trout LC50 (6.2 mg/L, Davies, 1980).

Toxic effects of uranium in mammals are related to kidney damage. The earliest symptoms are changes in chemistry of the blood and urine. Rats fed uranyl (UO_2^{+2}) for 11 months at a dose rate of 0.1 mg/Kg/day (0.08 mg U/kg/day) displayed no significant effects (HWC, 1980). However, dogs fed uranyl at a dose rate of 0.13 mg/kg/day (0.10 mg U/kg/day) for 21 months showed minor effects on the blood system (EPA, 1971). Based on animal experiments and blood and urine monitoring of human volunteers ingesting 0.07-0.10 mg U/kg, Health and Welfare Canada has estimated that daily ingestion of up to 0.07 mg should not have any toxic effect. Survey data indicate that approximately 50% of human uranium intake is by drinking. Therefore, assuming a water consumption of 2 L/day, the maximum acceptable uranium concentrations in drinking water was set at 0.02 mg/L (HWC, 1980). This concentration would result in less than 1% of the maximum permissible radiological dose equivalent commitment of 5 millisieverts per year from all sources (ICRP, 1979).

Uranium is not considered a chemical carcinogen (HWC, 1980). However, its radioactivity poses a finite cancer risk, assuming a zero dose threshold for radiological effects. Based on a cancer induction rate of about 10^{-4} fatal cancers per rem (Myers and Newcombe, 1980), consumption of uranium in drinking water at the maximum acceptable concentration of 0.02 mg/L would result in an increased fatal cancer risk of approximately 10^{-7} over a lifetime of water consumption.

The uranium levels recorded in Rabbit Lake mine and mill effluent stream as it flows into Hidden Bay, the mid-Hidden Bay waters and upstream in Umpherville River waters over the period of this study are presented in Table 2.2.

Conclusion

The above data indicate that uranium levels in water from Hidden Bay on average have not exceeded drinking water limits over the operation of the mine and mill, but have during peak periods exceeded the objectives. Maximum levels reported have not exceeded limits set for protection of wildlife, although exceedence may have occurred on occasion. It is suspected that there may have been some data reporting or analytical errors during the period of record in the Naquadat database. Upstream Umpherville River water does not exceed limits for drinking water or protection of wildlife.

The average concentration of uranium in Hidden Bay for the period 1980-1984 of close to 10 ug/L (9.2 ug/L) represents a safety factor of on the order of two times relative to the criteria of 20 ug/L. It should be noted that the average value has several less than numbers incorporated into it and, accordingly, the actual average value is expected to be less than 10 ug/L. It is also suspected that there may be some high biasing in the reporting of uranium data analyzed in water. In 1985, uranium values reported in the Umpherville River have been increasing with no known cause. This is presently being investigated as to whether it is of an environmental or analytical nature.

2.2.2 Arsenic

Arsenic is commonly found in water, soil and food. Concentrations in water analyzed from 5,400 rivers ranged from 0.001 mg/L to 0.05 mg/L (WQB, 1977) while lake samples analyzed during the same period (1972-1977) ranged from 0.005 mg/L to 0.02 mg/L.

The World Health Organization (WHO) determined the maximum allowable intake of arsenic to be 3.5 mg/day/70 kg/person (CPHA, 1977). The daily total intake of arsenic by North Americans has been estimated as 0.03-0.02 mg/day/person (Smith *et al.*, 1973; Jelinek and Corneliussen, 1977) which represents a 100 times lower intake than the WHO maximum level. Certain populations in California have reportedly used drinking water with 0.12 mg As/L with no ill effects (Goldsmith, 1972).

TABLE 2.2: URANIUM VALUES REPORTED FOR WATERS IN THE VICINITY OF THE RABBIT LAKE MINE AND MILLING FACILITIES

	Effluent Stream Entering Hidden Bay		Mid Hidden Bay		Umpherville River Discharge to Hidden Bay
	1980-84	1975-79	1980-84	1975-79	1977-84
Average (ug/L)	230.3*	293.9	9.2*	7.2*	2.72
High Value (ug/L)	2,090	6,000	124 ¹ (65)	130 ¹ (28)	7.8
Low Value (ug/L)	L 0.5	L 0.5	L 0.2	0.1	0.2

* Includes "less than" values.

¹ These values are questionable and are suspected of being two to ten times above actual values. The bracketed values are the next highest values in the data set.

The Canadian Public Health Association (1977) selected a maximum acceptable level of Arsenic of 0.05 mg/L in drinking water as a concentration which could represent up to 50% of a high daily intake of 0.10 mg per person yet had been demonstrated historically to be a level in drinking water at which no specific illness had been documented.

Arsenic has been identified as a potential carcinogen and on the assumption of a zero concentration threshold the estimated risk of increased cancers due to arsenic alone at the current drinking water limit of 0.05 mg/L would be about 10^{-2} according to the U.S. EPA (Federal Register, 1980). It should also be noted that arsenic has been shown to be an essential trace element for some animal species and may be for man.

Aquatic life is not affected until arsenic levels exceed 1.0 mg/L in water. Fish growth, energy resources and reproduction can be impaired at 1.0 mg/L arsenic (Speyer and Le Duc, 1975). Chronic lethality of daphnia, a fish food organism, occurs at 2.85 mg/L arsenic.

Arsenic levels have been measured in Rabbit Lake mine effluent creek where it discharges to Hidden Bay, the mid Bay area of Hidden Bay, and in the Umpherville River at the Highway 105 bridge crossing from 1975 to 1984. Table 2.3 compares the reported analytical data for these areas for the historical period of mine operation and for the more recent period.

Conclusion

The data in Table 2.3 indicate that arsenic levels in the effluent creek where it enters Hidden Bay did not exceed limits set to protect public health or levels identified as harmful to fish or fish food organisms. In fact, arsenic levels were near or below 1% of the recommended maximum limits for drinking water in Hidden Bay. All of the analytical data presented were at or near the detection limit and, at the detection levels used, there is no significant difference between the levels of arsenic entering Hidden Bay from the Umpherville River and the levels of arsenic entering Hidden Bay from the Rabbit Lake mining and milling effluent stream.

TABLE 2.3: ARSENIC VALUES REPORTED FOR WATERS IN THE VICINITY OF THE RABBIT LAKE MINE AND MILLING FACILITIES

	Effluent		Mid		Umpherville River
	Stream Entering		Hidden Bay		Discharge to
	Hidden Bay		Hidden Bay		Hidden Bay
	1980-84	1975-79	1980-84	1975-79	1977-1984
Average (mg/L)	0.0052*	0.0011*	NA	0.0009*	NA
High Value (mg/L)	L 0.02	0.004	L 0.02	0.0012	L 0.020
Low Value (mg/L)	L 0.0005	L 0.0005	L 0.0005	L 0.0005	L 0.007

NA = Not available (individual measurements below detection).

* Includes "less than" values.

2.2.3 Copper

Copper occurs naturally in igneous rocks at concentrations ranging from about 20 to 50 mg/kg (Cox, 1979). Limestones and sandstones contain about 5 mg copper/kg and soil concentrations and can range from 2 to 100 mg/kg with a mean of about 20 mg/kg (Bowen, 1966). Copper concentrations in Canadian rivers sampled between 1972 and 1977 ranged from 0.001 mg/L to 0.5 mg/L with 90% of the samples having concentrations below 0.011 mg/L (Environment Canada, 1977).

The toxicity of copper to aquatic life is dependant on the soluble copper concentration (Brown et al, 1974) while the complexed insoluble forms tend to be non-toxic (Stiff, 1971). Waters with a pH less than pH 6 (acidic) favour copper solubility and can increase the toxicity of total copper concentrations.

Algae growth was inhibited in species of algae when copper concentrations in water reached 0.6 to 0.8 mg/L whereas more sensitive species of algae found 0.1 to 0.3 mg Cu/L toxic (Whitton, 1970).

The toxicity of soluble copper to aquatic invertebrates varies according to species. *Daphnia* lethality occurs when copper concentrations range from 0.2 to 0.8 mg/L; aquatic insects exhibit mortality at 0.3 to 8 mg Cu/L; and snails find 0.01 to 0.8 mg Cu/L toxic (Spear and Pierce, 1979).

Fish successfully reproduce and grow when soluble copper concentrations are below 0.01 to 0.04 mg/L for fathead minnows (Mount, 1968; Pickering et al, 1977); below 0.05 to 0.02 mg/L for brook trout (Sauter et al, 1976; McKin and Benoit, 1971); and 0.01 to 0.02 mg/L for catfish (Sauter et al, 1976). The effect of copper on aquatic organisms is thus dependent, to a large degree, on its chemical state which is in turn controlled to some degree by pH. In neutral to slightly acidic waters, levels of copper should be below 0.002 mg/L to protect aquatic life, which is based on mean ambient concentrations in the Kenora, Ontario region, but would be exceeded in some areas of the Great Lakes. Existing local conditions should be considered in setting limits.

Copper in the human diet is essential to good health and Neri (1976) estimated the average Canadian consumes 2 to 4 mg daily through food and water. Water intake varies

TABLE 2.4: COPPER VALUES REPORTED FOR WATERS IN THE VICINITY OF THE RABBIT LAKE MINE AND MILLING FACILITIES

	Effluent Stream Entering Hidden Bay		Mid Hidden Bay		Umpherville River Discharge to Hidden Bay
	1980-84	1975-79	1980-84	1974-79	1977-84
Average (mg/L)	0.015*	0.003*	0.018*	0.006	0.004*
High Value (mg/L)	0.037	0.01	0.05	0.04	L 0.007
Low Value (mg/L)	0.002	L 0.001	L 0.002	L 0.001	L 0.001

* Includes "less than" values.

from 0.6 to 1.2 mg daily depending on water hardness (Neri, 1976). Excessive copper intake produces vomiting and diarrhea but is not toxic to humans until consumption reaches gram intake levels (NAS, 1977). Copper levels exceeding 1 mg/L may impair the taste of drinking water making detection of higher concentrations easily detectable. Copper exposure is not associated with increased risk of cancers (Federal Register, 1980). Canadian drinking water guidelines for copper have been set by Health and Welfare Canada at 0.5 mg/L.

The copper levels that have been measured in the Rabbit Lake mine and mill effluent where it discharges to Hidden Bay, mid area of Hidden Bay, and upstream in the Umpherville River are presented in Table 2.4.

Conclusion

The fact that both the average and high values for the mid portion of Hidden Bay are higher than for both the effluent stream and the Umpherville River suggests that the uncertainty associated with the copper analyses reported to date are on the order of four times at a value of 0.01 mg/L.

Notwithstanding this, the copper concentrations in Hidden Bay and the Umpherville River are 50 to 250 times lower than the Canadian drinking water guidelines (HWC, 1980) and would not constitute a threat to human health. Average copper concentrations are below levels toxic to fish and fish food organisms for effluent stream where it enters Hidden Bay and mid Hidden Bay conditions. High effluent stream concentrations approach toxic concentrations for fish and invertebrates, although they have not been observed to exceed drinking water guidelines. Based upon this information, it would not appear that copper has posed any direct risk to the natural or human populations of the Hidden Bay area over the life of the mining and milling operation at Rabbit Lake.

2.2.4 Lead

Lead is a common constituent of rock occurring at about 7 mg/kg in sandstones, 20 mg/kg in shales and ranges between 2 and 200 mg/kg in soils with an average value of 10 mg/kg (Turekian and Wedepohl, 1961). Concentrations of lead in Canadian river and lake waters sampled between 1972 and 1977 ranged from 0.001 to 0.05 mg/L dissolved lead

(0.45 μm filtered) and L 0.001 to 0.1 mg/L for extractable lead (Environment Canada, 1978). A median value of 0.005 mg/L has been reported for river water (Bowen, 1966).

The toxicity of lead to algae varies according to the pH of the water and phosphorus availability. Algae growth can be inhibited when lead concentrations are between 0.5 mg/L (acidic-phosphate limited) and 3 mg/L in alkaline waters (Monahan, 1976).

Invertebrates have a wide range of sensitivity which can also be affected by water hardness. Lead is toxic to Gammarus at 0.028 mg/L (Sartory and Lloyd, 1976), Daphnia at about 0.5 mg/L (Biesinger and Christensen, 1972; Baudouin and Scoppa, 1974) and Asellus at 0.28 mg/L, although the latter can develop tolerance to concentrations ten times higher with pre-exposure (Brown, 1976).

Other benthic invertebrates are more tolerant of lead; mayfly 3.5 to 16 mg/L (Nehring, 1976; Warnick and Bell, 1969); stonefly 64 mg/L (Warnick and Bell, 1969) and caddisfly 32 mg/L (Warnick and Bell, 1969). Snails do not find lead toxic until levels exceed 14 to 71 mg/L (Cairns et al., 1976).

Brook trout can develop curved backbones and stunted growth over three generations if exposed to 0.058 to 0.119 mg/L total lead (0.039 to 0.084 mg/L dissolved lead) in relatively soft water (Holcombe et al., 1976). Rainbow trout fry demonstrated reduced survival when lead levels exceeded 0.0041 to 0.0076 mg/L (Davies et al., 1976).

The level of lead in water which is considered to have no significant effect on aquatic organisms is set at 0.005 mg/L in soft water and 0.01 mg/L in hard water (hardness greater than 95 mg/L CaCO_3). For toxicity evaluation purposes, the waters of Hidden Bay should be considered as soft waters.

Lead is an accumulative toxicant in humans that can affect blood, neural, kidney and reproductive systems when intake is high. The average daily intake in Canada is 0.180 mg with about 0.02 mg coming from water (Leah, 1976). Both the WHO and U.S. EPA determined that 0.3 to 0.4 mg intake per day would not lead to excessive body burdens (Mahaffey, 1977a; EPA, 1976). The recommended maximum acceptable concentration of lead in drinking water should not exceed one-third to one-quarter the daily total intake based on 2 L of water consumption per day. The Canadian drinking water objective is then 0.05 mg/L.

TABLE 2.5: LEAD VALUES REPORTED FOR WATERS IN THE VICINITY OF THE RABBIT LAKE MINE AND MILLING FACILITIES

	Effluent		Mid		Umpherville River
	Stream Entering		Hidden Bay		Discharge to
	Hidden Bay ¹		Hidden Bay		Hidden Bay
	1980-84	1975-79	1980-84	1974-79	1977-84
Average (mg/L)	0.053*	0.012*	0.025*	0.007*	0.016*
High Value (mg/L)	0.201	0.10	L 0.08	0.027	0.030
Low Value (mg/L)	L 0.002	0.001	L 0.002	0.001	L 0.002

* Includes "less than" values.

¹ Fillion report on analytical procedures and data for lead suggests that many of the high values in the 1982 to February 1984 period are questionable.

Conclusion

The data as reported in Table 2.5 are based upon reported analytical data. A recent investigation into this data (Filion, 1985) has shown that the majority of the data reported were biased high due to sulphate interference and not taking background corrections into account when calculating lead concentrations in the water. Based upon the limited data that are available, it would appear that the average value of lead in the effluent stream entering Hidden Bay, Hidden Bay itself and the Umpherville River where it enters Hidden Bay was on the order of 0.005 mg/L and that it would be very difficult to distinguish any significant input to Hidden Bay from the Rabbit Lake mining and milling operation. If levels of lead did not significantly exceed 0.005 mg/L, it could be concluded that lead from the Rabbit Lake facility does not pose any significant threat to either natural aquatic or human populations of the Hidden Bay or Wollaston Lake area.

2.2.5 Nickel

Nickel occurs more commonly than arsenic, copper or lead, being present in sandstone at about 1 mg/Kg, in basalt and gabbro at about 160 mg/kg and 2,000 mg/kg in igneous rocks (Taylor, 1964; NAS, 1975). Nickel concentrations in Canadian rivers sampled between 1972 and 1977 ranged between 0.001 mg/L and 0.3 mg/L with 90% of the concentrations less than 0.012 mg/L (WQB, 1977). Average drinking water concentrations were reported by Neri (1976) from 233 Canadian locales to range from 0.0029 to 0.0072 mg Ni/L.

Algae growth is unaffected when nickel levels are below 0.25 mg/L (Stokes, 1973). Daphnia magna reproduction was impaired when nickel levels exceeded 0.03 mg/L (Biesinger and Christensen, 1972). Larger aquatic invertebrates are more tolerant, finding nickel toxic at 33.5 mg/L (stonefly) and 4 mg/L (mayfly) in soft water (Warnick and Bell, 1969). Fish toxicity data indicate that reproduction is impaired when levels exceed 1 mg/L in water (Pickering, 1974). The level of nickel in aquatic environments should not exceed 0.025 mg/L in soft water or 0.25 mg/L in hard water (hardness greater than 150 mg/L CaCO_3). Hidden Bay waters are considered to be in the soft water category for nickel toxicity considerations.

Nickel in the human diet is essential to good health (Mertz, 1974), and is associated with many important enzyme systems in the body (Underwood, 1971). Deficiencies of nickel in

the diet can result in liver dysfunction, skin discolouration and dermatitis, as well as impaired reproduction. Dietary requirements extrapolated from animal studies would suggest 0.05 to 0.08 mg Ni/kg is required by man (Nielsen and Sandstead, 1974). Levels of nickel in animal diets were not toxic until doses from 5 to 1,000 mg/kg were reached (NAS, 1975).

The Environment Canada (1979) surface water guideline for drinking water was derived by taking 1/25 of the lowest toxic level from animal studies ($5/25 = 0.2$ mg/L) and assuming that conventional treatment would remove 20%, therefore nickel in raw drinking water should not exceed 0.25 mg/L ($0.2/0.8 = 0.25$).

Reported nickel levels in the Rabbit Lake effluent stream where it enters Hidden Bay, mid-Hidden Bay and in the Umpherville River where it discharges to Hidden Bay are shown in Table 2.6.

Conclusion

Drinking water guidelines are not exceeded during any study period in Hidden Bay, the Umpherville River discharging to Hidden Bay, nor the effluent stream where it discharges to Hidden Bay. The data also suggest that fish reproduction would not be affected based on reported nickel concentrations. Peak nickel concentrations in the Hidden Bay waters are reported as value of less than 0.02 mg/L. The data suggest that the mining and milling operation at Rabbit Lake may be adding detectable levels of nickel to Hidden Bay, but that these levels pose no significant risk to human or fish populations.

2.2.6 Selenium

Selenium is widely distributed in the environment at low levels. Typical concentration ranges are 0.004 to 1.5 mg/kg in igneous rocks (Lakin, 1973), 0.1 to 1,200 mg/kg in soil (Johnson, 1976), 0.1 to 1.5 ug/L in freshwater (Traversy *et al.*, 1975), and 0.2 to 2.0 mg/kg in freshwater sediments. Natural abundance in the earth's crust has been estimated at 0.09 mg/kg (CRC, 1970). Selenium is very insoluble in elemental form, and is primarily available to man and biota as selenite and selenate. Selenate is most soluble and may be formed by oxidation of selenite above pH 8 (Lakin, 1973).

TABLE 2.6: NICKEL VALUES REPORTED FOR WATERS IN THE VICINITY OF THE RABBIT LAKE MINE AND MILLING FACILITIES

	Effluent		Mid		Umpherville River
	Stream Entering		Hidden Bay		Entering
	1980-84	1975-79	1980-84	1974-79	Hidden Bay 1977-84
Average (mg/L)	0.042*	0.035	0.009*	0.008*	0.012*
High Value (mg/L)	0.201	0.123	L 0.02	0.017	0.014
Low Value (mg/L)	0.01	0.002	L 0.001	0.002	L 0.001

* Includes "less than" values.

The threshold water concentrations for toxic effects in aquatic biota vary among species from 0.04 mg/L in fish (trout) embryos and fry (Davies and Goettl, 1975) to 2.5 mg/L in cladocera (Daphnia) and algae (Scenedesmus) (Bringmann and Kuhn, 1959 in Environment Canada, 1979). Hutchinson (1973) reported growth inhibition in algae at 0.05 mg/L. Lethality thresholds have been estimated at about 1 mg/L in zebrafish (Niimi and Leham, 1975), goldfish (Weir and Hine, 1970) and fathead minnows (Cardwell et al., 1976). Acute 96-hour LC50 concentrations range from 2.9 mg/L for fathead minnow fry to 14.3 mg/L for adult brook trout (Environment Canada, 1979).

Environment Canada (1979) has recommended a water quality objective of 0.01 mg/L for protection of aquatic biota and wildlife. This objective is based on the lowest recorded acute LC50 of 2.9 mg/L for fathead minnows, adjusted by an application factor of 0.0033. The application factor is derived from the no-effect level in rainbow trout (0.04 mg/L) as a fraction of the LC50 (12.5 mg/L). The U.S. Environmental Protection Agency (EPA, 1980) recommended a criteria of 0.035 mg/L as selenite for protection of fresh water aquatic life.

Symptoms of selenium toxicity in mammals include liver, heart and gastrointestinal damage, loss of hair and nails, visual impairment and paralysis (NRC/NAC, 1975; HWC, 1980). Selenium is not considered to be a chemical carcinogen and may, in fact, be anticarcinogenic (NRC/NAC, 1975; IARC, 1975; Schrauzer, 1976; Schrauzer et al., 1977). It plays an essential role in peroxidase enzyme function and may be involved in membrane function and protein synthesis (Environment Canada, 1979; HWC, 1980). Schrauzer et al. (1977) have estimated a human dietary requirement of 0.2 to 0.3 mg/day. A wide variety of symptoms have been attributed to selenium deficiency.

The threshold selenium intake for human health impairment has been estimated at 0.5 mg/day (Sakurai and Tsuchiya, 1975). Reduced weight gain in rats has been reported at this rate of intake. Based on this intake threshold, an average water consumption of 2 L/day, and an estimated 20% of intake from drinking, Environment Canada (1979) has recommended a maximum acceptable selenium concentration of 0.05 mg/L in raw public water supplies without advanced water treatment facilities. The International Joint Commission (IJC, 1976) recommended a selenium limit of 0.01 mg/L for raw water supplies.

The U.S. Environmental Protection Agency (EPA, 1976, 1980) and Health and Welfare Canada (HWC, 1980) have recommended a maximum acceptable selenium concentration of 0.01 mg/L in drinking water, a conservative objective which may be based on potential interactions between selenium and other compounds (HWC, 1980), although no specific rationale is developed. Liver disfunction has been reported in rabbits drinking water at this concentration (Pletnikovan, 1970). However, this result is questionable due to lack of experimental control (HWC, 1980).

The selenium concentrations reported in the effluent stream where it discharges to Hidden Bay, mid-Hidden Bay and in the Umpherville River where it discharges to Hidden Bay are shown in Table 2.7.

Conclusion

The results indicate that selenium concentrations in Hidden Bay have been within drinking water objectives from 1980 to the present, although poor detection limits on some analyses do not allow this to be confirmed in all cases. Some high values in the period 1974 to 1979 were reported which exceeded both drinking water guidelines and guidelines for the protection of aquatic life. There is no indication that mine effluent is contributing any significant amounts of selenium to Hidden Bay. The fact that Hidden Bay has higher reported values of selenium than both the effluent stream entering Hidden Bay and the Umpherville River entering Hidden Bay suggests a high degree of analytical uncertainty associated with the selenium data. In order to achieve precise and accurate selenium data at the levels expected here, the analyses for selenium should be carried out using a hydride generation procedure which typically gives a detection limit of 0.0005 mg/L. The fact that detection limits of 0.02 mg/L or about 40 times higher than that expected suggests inappropriate analytical methodology is being used.

2.2.7 Vanadium

Vanadium is often found in titanium and uranium ores, some crude oils and coal. Concentrations of vanadium range from 0.3 to 200 ug/L in fresh water (Schoeder, 1970; NAS, 1974). Municipal water may contain 1 to 6 ug V/L (Beliles, 1978).

**TABLE 2.7: SELENIUM VALUES REPORTED FOR WATERS IN THE VICINITY OF
THE RABBIT LAKE MINE AND MILLING FACILITIES**

	Effluent Stream Entering Hidden Bay		Mid Hidden Bay		Umpherville River Entering Hidden Bay
	1980-84	1975-79	1980-84	1974-79	1977-84
Average (mg/L)	0.005*	0.002*	0.007*	0.004*	NA
High Value (mg/L)	L 0.01	L 0.002	L 0.02	0.061	L 0.02
Low Value (mg/L)	L 0.001	L 0.001	L 0.001	L 0.001	L 0.008

NA - data not appropriate for inclusion.

* Includes "less than" values.

Vanadium in water below 20 to 40 ug/L can stimulate growth of some algae while above that concentration phytoplankton diversity can decrease (Patrick, 1979). Levels lethal to fish range from 0.4 to 55 mg V/L, depending on the species exposed and the water hardness. Fathead minnow, bluegill sunfish and carp sensitivities occur within the 5 to 55 mg V/L range (Tarzwell and Henderson, 1960; Knudtson, 1979).

Human average daily dietary intake is 20 ug V (Hopkins and Mohr, 1974; Myron et al., 1978). The estimated lethal level for humans is 120 ug V/kg (Faulkner-Hudson, 1964). Chronic exposure of mammals to high non-lethal levels of vanadium produce detrimental changes in blood chemistry (Roshchin, 1967). Vanadium has also been shown to inhibit ATPase activity (Cantley et al., 1977, 1978) which affects energy systems of general metabolism. While vanadium has been demonstrated as essential for health in birds and mammals (Hopkins and Mohr, 1977), but has not been proven essential for humans.

Vanadium has been demonstrated as a bacterial mutagen in the Ames test (Kanematsu and Kada, 1978) and capable of DNA and chromosomal spindle damage (Conde and Walnick, 1978).

Drinking water and aquatic life guidelines have not been set by Environment Canada, the U.S. EPA or the World Health Organization. The U.S. Department of Commerce (1977) recommends vanadium not exceed 7 ug/L in ambient water to protect human health and 75 ug/L to protect aquatic life.

Reported levels of vanadium in the effluent stream where it discharges to Hidden Bay, mid-Hidden Bay and Umpherville River discharging to Hidden Bay are presented in Table 2.8.

Conclusion

The analytical methodology used to determine the levels of vanadium in the waters around the Rabbit Lake mine and mill site are not sensitive enough to determine whether or not the amount of vanadium present in the water exceeds recommended drinking water guidelines and guidelines recommended for the protection of aquatic organisms. Similarly, no statement can be made as to whether or not the Rabbit Lake mine and mill is discharging levels of vanadium which may be significantly contributing to levels in

TABLE 2.8: VANADIUM VALUES REPORTED FOR WATERS IN THE VICINITY OF THE RABBIT LAKE MINE AND MILLING FACILITIES

	Effluent		Mid		Umpherville River
	Stream Entering Hidden Bay		Hidden Bay		Discharging to Hidden Bay
	1980-84	1975-79	1980-84	1974-83	1977-84
Average (mg/L)	0.04*	0.03	NA	0.02*	0.34**
High Value (mg/L)	L 0.2	L 0.10	L 0.6	0.01	1.0**
Low Value (mg/L)	0.01	0.01	L 0.002	L 0.002	L 0.005

NA - not available as individual measurements are below detection limits.

* Includes "less than" values.

** The 19 February 1984 sample was reported as 1.0 mg/L, while the 20 August 1984 sample was reported as L 0.005 mg/L. Since there is no known or suspected pulse source of vanadium in the upper Umpherville River watershed, sample contamination or analytical error is suspected. This high value has also affected the reported average value.

Hidden Bay. The extreme levels in detection limit fluctuations of on the order of 300 times (L 0.6 to L 0.002) in Hidden Bay from 1980 to 1984 suggest marked changes in analytical procedures or techniques. It is strongly recommended that a much higher degree of consistency and associated accuracy and precision be required for future vanadium analyses.

2.2.8 Zinc

Zinc is commonly present in shales (95 mg/kg), sandstones (16 mg/kg) and limestones (20 mg/kg) (Turekian and Wedephol, 1961). The average concentration in crustal materials is 70 mg/kg and ranges from 5 to 200 mg/kg (Taylor, 1964; Aylett, 1973; Brooks, 1977).

Concentrations of zinc in Canadian surface waters ranged from L 0.001 to 3.0 mg/L with 90% of the samples collected between 1972 and 1977 less than 0.06 mg Zn/L.

The toxicity of zinc to aquatic organisms is greater in soft water than hard water (Pagerkopf, 1976). Fish egg hatching appeared to be the most sensitive response and varied in soft water compared to hard water. The highest tolerable concentration for rainbow trout eggs in soft water (30 mg CaCO_3/L) was 0.036 to 0.071 mg Zn/L while flagfish eggs tolerated 0.32 to 0.64 mg Zn/L in hard (350 mg CaCO_3/L) water (Goettl et al., 1976). Daphnia reproduction was reduced by 16% at 0.07 mg Zn/L after three weeks exposure in soft water (Biesinger and Christensen, 1972). Algae growth inhibition has also been reported at levels above 0.03 mg Zn/L (Bartlett et al., 1974). Review of toxicity data indicate that for waters of intermediate hardness (less than 120 mg CaCO_3/L) zinc levels should not exceed 0.05 mg/L to provide an adequate margin of safety for aquatic life. The waters of Hidden Bay are considered to be soft waters, and a level of 0.05 mg/L zinc should be considered as a maximum value not to be exceeded.

Zinc is essential to human health and is required in enzyme function, protein synthesis, carbohydrate metabolism, amino acid metabolism and DNA/RNA synthesis (Halsted et al., 1974; Eichhorn, 1975; Sandstead, 1975). The average daily intake of zinc by Canadians is 14.6 mg with 98% taken from food and 1.5% from drinking water (Schrauzer et al., 1977; Clemente, 1976). Very high levels (4,000 - 5,000 mg/kg) of zinc intake are required before deleterious effects are observed (Underwood, 1971).

Based on the beneficial effects of zinc and the moderately low levels of zinc in natural waters, the drinking water level has been set at 5 mg/L (HWC, 1980) which is 100 times higher than the level recommended for the protection of the most sensitive forms of aquatic life in soft waters such as found in Hidden Bay.

The zinc concentrations measured upstream in Umpherville River, mid-Hidden Bay and the effluent stream where it discharges to Hidden Bay from the Rabbit Lake facility are presented in Table 2.9.

Conclusions

The average levels of zinc measured in all of the waters, including the effluent discharge to Hidden Bay, are less than 1% of drinking water maximum guidelines and below those levels set for the protection of aquatic life in soft waters. The fact that the average value and the maximum value reported for Hidden Bay both exceed the average and maximum values for the effluent stream entering Hidden Bay and the Umpherville River discharging to Hidden Bay suggest a high degree of uncertainty associated with the zinc analyses. The maximum reported values for both the effluent stream entering Hidden Bay (0.1 mg/L) and Hidden Bay itself (0.2 mg/L) are above the 0.05 mg/L recommended for the protection of aquatic life. The uncertainty associated with these values is suspected of being quite high, and their significance is questionable.

TABLE 2.9: ZINC VALUES REPORTED FOR WATERS IN THE VICINITY OF
THE RABBIT LAKE MINE AND MILLING FACILITIES

	Effluent Stream Entering Hidden Bay		Mid Hidden Bay		Umpherville River Discharging to Hidden Bay
	1980-84	1975-79	1980-84	1974-79	1977-84
Average (mg/L)	0.028*	0.011*	0.032*	0.011*	0.014*
High Value (mg/L)	0.10	0.023	0.20	0.14	0.032
Low Value (mg/L)	L 0.001	L 0.005	L 0.002	L 0.001	0.005

* Includes "less than" values.

3.0 SUMMARY OF ENVIRONMENTAL MONITORING DATA

During the preparation of this study, all of the environmental monitoring data that were in the files of the Saskatchewan Mines Pollution Control Branch concerning the Rabbit Lake operation were reviewed. The vast majority of these data were collected as part of routine monitoring programs and focussed on those parameters which have license stipulations. Several special studies have also been carried out during the past ten years during which mining and milling operations have been carried out at Rabbit Lake. These special studies have considered, in addition to water quality, environmental compartments, such as fish and sediment, and radionuclides and chemical elements not routinely monitored.

In assembling the summary tables presented in the text of this report, data were abstracted primarily from the routine monitoring studies and, where data were not available from routine monitoring, data were abstracted from special studies. In some instances, such as for polonium-210, no data were found to be available in certain areas and concentrations were estimated based upon assumptions of secular equilibrium for water and sediments.

For presentation purposes in this section, the summary tables present data that have been selected from monitoring and special studies as being the most probable value, except where otherwise noted. For example, there are a large quantity of data that are reported as 'less than' a certain value. The magnitude of this less than value is a reflection of both the quantity of sample available for analysis and the sensitivity of the particular analytical technique employed. In cases where the data for a particular environmental compartment were presented as absolute values at a value less than the routinely reported less than value, this absolute value was chosen for assessment purposes. Differences in this area between some routinely reported less than values and other absolute or lower less than values often were as great as 100-fold. This approach varies from that used in Section 2 where the data are presented in the tables as reported and, as such, reflect analytical uncertainty.

In cases where duplicate sets of analyses were available for assessment on the same environmental compartment (e.g., water or fish), the most sensitive value was selected for presentation purposes. That is, if two values are presented such as L 0.1 and another

for the same sample as 0.02, the latter value was selected as the less than 0.1 value could in reality be 0.02. In many cases, a lack of sensitivity or accuracy in the analysis could be traced to a variety of causes, such as the analysis of raw samples without pre-concentration, failure to account for interferences in the analysis which could lead to higher detection limits and, related to this, failure to carry out background corrections. The use of less sensitive instrumentation is suspected in some instances. In other cases, lack of analytical sensitivity may be related to lack of sample quantity.

In the recommendations section of this report, recommendations are made as to what levels of precision and accuracy should be required on routine monitoring data in order to ensure that any changes in the environment as low as 10% of the 'safe' level can be routinely detected in order to allow accurate monitoring and adequate time to proceed with remedial action if it is warranted.

Data from the three major aquatic environment compartments, sediment, water and fish, have been reviewed and data selected for presentation in this section has been converted to a similar presentation format. Much of the raw data that are presented in the various reports has been presented in a variety of ways. For example, the data on radionuclide and trace element concentrations in fish tissue may be presented on the basis of ash weight, dry weight or fresh weight. The summary data in this study have converted all of these data to a fresh weight basis in order that an assessment can be carried out. The following sections discuss the data upon which the environmental evaluation has been carried out.

3.1 Water Quality

The amount of a chemical or radioactive substance present in a water body can affect natural aquatic populations in one of two ways. At very high levels, there can be short-term acute poisoning of fish and other aquatic organisms or man. At lower levels, there may be a much longer-term chronic poisoning in which it takes many months or years for symptoms to manifest themselves in individuals or the populations. Water quality and radionuclide data were reviewed in order to evaluate the potential for both of these types of effects.

The water quality data that have been reviewed around the Rabbit Lake mine site are summarized in Table 3.1. These data are abstracted from data in the Esquadat database of Saskatchewan Environment. The data presented include a control area represented by the Umpherville River where it discharges to Hidden Bay, the treated effluent stream flowing into Hidden Bay, the mixed waters of Hidden Bay, the inflow from Link Lakes to Pow Bay and the mixed waters of Pow Bay. These data thus represent a control, all of the waters entering the Wollaston Lake Basin that may have been significantly influenced by the Rabbit Lake mining and milling facility, and the immediate receiving waters of Wollaston Lake (Hidden and Pow Bays). The final column in Table 3.1 is a summary of the water quality objectives for the elements reviewed that are suggested to protect the most sensitive forms of aquatic life under the most stressful environmental conditions. These values are, for the most part, derived from laboratory toxicity studies in which the test animals are exposed to the most toxic form of the particular element. Under natural field conditions, a certain percentage of the element is usually present in some type of complexed or bound form and, as such, is not toxic to aquatic organisms. Routine monitoring data does not allow the distinction between complexed and free forms of a particular element other than the generality that the higher the pH and conductivity, the less toxic a particular element will be. The only exception to this is ammonia. In this instance, the higher the pH the more toxic the ammonia is.

The data presented in Table 3.1 are long-term median values. The median values were selected in order to attempt to remove some of the statistical bias created in the data when mean values are employed. The median value is the most frequently reported number. The analytical data contain many 'less than' values which mean that the analytical method employed could not detect the particular compound or elements presence at the particular 'less than' detection limit reported. The presence of these 'less than' values in the data result in the statistical values reported in Table 3.1 being higher than would actually be the case if absolute values were reported.

A review of the highest values obtained during the operation of the Rabbit Lake facility over the last ten years has shown that the only compound which has posed an acutely toxic threat to aquatic life has been ammonia. In the late 1970's, and early 1980's, the levels of ammonia in some parts of Hidden Bay near the effluent discharge to Hidden Bay contained levels of ammonia which may have been acutely toxic to fish. There are no documented reports of fish kills from this period. It is suspected that, since fish can

TABLE 3.1: SUMMARY OF WATER QUALITY PARAMETERS IN DISCHARGES AND LOCAL WATERS
LONG-TERM MEDIAN VALUES

Parameter	Umperville River Discharge to Hidden Bay		Effluent Discharge to Hidden Bay		Mid Hidden Bay		Link Lakes Discharge to Pow Bay		Mid Pow Bay		Water Quality Objectives for the Protection of Aquatic Life
	April 1977- Aug 1983	Aug 1983	to Hidden Bay		Hidden Bay		to Pow Bay		Pow Bay		
			Feb 1975- Aug 1983	Jan 1980- Dec 1984	Aug 1974- Jun 1983	Jan 1980- Aug 1984	Jan 1981- Dec 1984	Jan 1975- Aug 1983	Jan 1980- Aug 1984		
Radionuclides											
Uranium (ug/L)	L 1	33	26.5	3.0	3.0	3.0	135	0.6	2.5		
Thorium-230 (Bq/L)		0.013	0.01				0.014	L 0.005	L 0.005		
Radium-226 (Bq/L) Total	0.007	0.02	0.02	0.007	0.007	0.007	0.109	0.011	0.01		
Lead-210 (Bq/L)		0.044	0.06				L 0.180	0.08	0.11		
Trace Elements											
Arsenic (ug/L)	L 7	L 1	2	L 1	L 4	L 4	2.3	L 0.5	L 4.5	100	
Mercury (ug/L)	L 0.04	L 0.05	L 0.05	L 0.05	0.05	0.05	L 0.05	L 0.05	L 0.04	0.5	
Copper (ug/L)	L 4	4	15	3	16	16	13	6	L 20	2	
Lead (ug/L)	13	9	L 30	5	17	17	14	3	L 30	5	
Nickel (ug/L)	L 7	32	36	6	8	8	L 10	4	L 10	25	
Selenium (ug/L)	L 8	1	4	L 2	4	4	1	L 2	6	35	
Zinc (ug/L)	10	10	20	5	12	12	18	9	12	50	
Vanadium (ug/L)	L 20	10	20	L 10	10	10	L 10	L 10	50	75	
Chloride (mg/L)	1	24	30	1	1	1	2	L 1	1		
Sulphate (mg/L)	L 1	448	830	7.2	7.2	7.2	15	L 1	3.7		
Conductivity (uS/cm ²)	28	1,000	1,622	28	45	45	III	35	36		
Ammonia (N) (mg/L)	L 0.1	23.6	31	0.17	0.19	0.19	L 0.20	0.08	L 0.1	5	
pH	7.2	6.6	6.5	7.4	7.4	7.4	7.3	7.0	7.0		

L = less than.

sense ammonia in the water, any fish near the effluent discharge to Hidden Bay may have simply swum away to 'cleaner' water and not been affected by the ammonia. At present, the mill is changing its process from an ammonia-based product to a magnesium-based product. When this change is complete, no further problems with ammonia releases are expected to occur.

The levels of all of the other trace elements and radionuclides are at levels below where any acutely toxic effect may be expected to occur. Rather, the chronic effects that are present at lower levels are more subtle in nature, and do not show up as 'fish kills' but rather as increased susceptibility to disease, lowered reproductive success or some other form of reduced population vigor. No chronic effects are expected to occur at the levels that have been monitored to date, and no biological data have been collected which would suggest that these effects have occurred or are occurring.

The levels of all of the radionuclides monitored are many times below where any form of radio-toxic effect would be noticed in the aquatic population. As discussed in Section 4.0, the levels of radionuclides in all environmental compartments (water, sediment and the animals themselves) would have to increase over 100 times before any chronic effects would be expected to appear. A detailed discussion of radiation doses to aquatic populations is presented in Appendix I. The data in Table 3.1 suggest that levels of copper and lead in the environment are of the most potential concern. The range of total copper measured in the effluent stream discharging to Hidden Bay was reported to range from 2 to 37 ug/L over the 1980 to 1984 period and 1 to 37 ug/L over the 1975 to 1983 period. These fluctuations could be actual fluctuations in effluent chemistry, or may reflect interferences if an alkali metal buffer was not used in the analysis. This is suggested by the fact that the median value for Hidden Bay is 16 ug/L, while the median value for the effluent discharge to Hidden Bay is 15 ug/L for the 1980 to 1984 period. Hidden Bay waters consist of a mixture of effluent flowing into Hidden Bay and dilution water from the Umpherville River. This dilution on a long-term average basis has been on the order of 100:1. Thus, even if the effluent levels of copper were continually at the highest level reported of 37 ug/L and the levels of copper in the Umpherville River are assumed to be 4 ug/L rather than the 'less than' 4 ug/L reported, the highest level to be expected in Hidden Bay would be no more than 5 ug/L based upon mass balance considerations. Careful attention should be paid to carrying out copper analyses and, if mass balance inconsistencies continue to appear, the quality of the data should be investigated.

Lead is the other element of potential concern. In this instance, the same inconsistency in the mass balance suggests that the data reflect analytical fluctuations rather than actual fluctuations in effluent chemistry or the relationship between background chemistry and the water quality of Hidden Bay. The nature of these analytical problems have been discussed in another study (Filion, 1985). The conclusion of this study was that lead levels in both the background Umpherville River and the effluent stream entering Hidden Bay and the waters of Hidden Bay likely have not significantly exceeded 5 ug/L. At these levels, no adverse effects on the natural environment or human populations may be expected.

The level of nickel in the effluent stream discharging to Hidden Bay which has a long-term median value of near 35 ug/L shows a reasonable mass balance relationship with the waters of Hidden Bay. This suggests that the nickel values, as presented in the available data, are reasonably accurate and that any environmental effects would be expected to be restricted to the area immediately adjacent to the effluent stream discharge to Hidden Bay and not manifest themselves in the broader area of Hidden or Pow Bays. At the levels of nickel reported near the effluent stream discharge to Hidden Bay, it would be extremely difficult to distinguish any environmental effect from natural background fluctuations, and any local chronic effect would be environmentally insignificant.

The median mercury values presented in Table 3.1 suggest that the level of mercury in both the effluent from the Rabbit Lake facility and in the receiving waters of Pow and Hidden Bays are well below levels at which any concern would be justified. A review of the raw data reported by Eldor Mines suggest, however, that mercury levels in Hidden Bay have been slowly increasing from 1982 to 1984 and dropping in 1985. This is at present unexplained as the average levels of mercury in the effluent discharge to Hidden Bay are lower than the values reported for Hidden Bay itself. It is suspected that the levels of mercury reported for Hidden Bay in these data are incorrect and that, by inference, the levels of mercury reported in the effluent stream discharge to Hidden Bay are suspect. As in the case of other elements where mass balance inconsistencies such as this are present, the nature of the quality control/quality assurance programs need to be looked into and upgraded.

The other trace elements and chemical parameters in these waters are at levels which are consistent with the expected dilution in the receiving waters and considering a

reasonable degree of uncertainty in the analytical data. A review of the sulphate data in Table 3.1 provides an example of the utility of using a mass balance approach to validate the data. The flow data available for the period up until 1984, prior to the pit dewatering water from the Collins Bay deposit being treated, indicated an effluent dilution in Hidden Bay of on the order of 100:1. Since mixing in Hidden Bay is not always uniform or complete, one would expect some variation from this figure of perhaps 50% in either direction. Thus, if an observed concentration in Hidden Bay reflects a dilution of between 50:1 to 150:1, the value would be considered reasonable for the period 1974 to 1984. The sulphate dilution ratios for the two periods recorded in Table 3.1 are 72:1 and 134:1, with an average of 103:1 after background correction of 1 mg/L sulphate. The sulphate values thus provide a good numerical cross-check on what levels of effluent parameters should be expected in the waters of Hidden Bay.

3.2 Sediment Quality

The sediments of a particular waterbody reflect both the chemical composition of the parent geological material laid down in the original lake basin and the chemical characteristics of particulate materials that settle to the sediments from the water column. The sediments of Hidden Bay may be expected to reflect material washed in from the Umpherville River, suspended solids washed in from the effluent and other small streams entering the bay and solids (dead algae and zooplankton) which are produced and settle within the bay itself. Although no sedimentation studies have been carried out in Hidden or Pow Bays, it is estimated that sedimentation rates in these bays are on the order of 1 to 5 mm/a. This would result in an overall accumulation of between 1 to 5 cm of sediment in Hidden and Pow Bays over the ten years of the Rabbit Lake facility operation. Information supplied by Eldor Mines shows that the sediment analyses presented in Table 3.2 for 1978 and 1984 are based on collections of the surface inch (4 to 5 cm) of sediment which has been deposited since the Rabbit Lake facility began operations. It has been recognized by Eldor Mines that samples collected with an Ekman dredge collect a bulk sample on the order of 10 to 15 cm in depth, and that it is necessary to separate the recent surficial sediments from the older, deeper sediments. The raw data from which the data in Table 3.2 have been abstracted suggest spatial variations within Hidden Bay at a given point in time on the order of ten times for both radionuclides and trace elements. These facts must be taken into account as they will influence the significance of the sediment chemistry data as it relates to operational effects of the Rabbit Lake facility on Hidden and Pow Bays.

TABLE 3.2: SEDIMENT, RADIONUCLIDE AND TRACE ELEMENT DISTRIBUTION
IN HIDDEN AND POW BAYS

Parameter	Hidden Bay			Pow Bay		
	1972 ¹	1978 ²	1985 ³	1972 ¹	1978 ²	1984 ³
Radionuclides						
Uranium (ug/g)	6.5	8.5	124	81.6	8.6	16.4
Thorium-230 (Bq/g)	0.065	0.12	0.04	0.22	0.07	
Radium-226 (Bq/g)	0.08	0.11	0.14	0.28	0.06	0.13
Lead-210 (Bq/g)	0.26	0.21	0.52	0.46	0.08	0.083
Polonium-210 (Bq/g)	0.05			0.12		
Trace Elements (ug/g)						
Copper	11	5	19	10	7	
Zinc	210	36		300	40	
Nickel	13	32.2	28	20	26	
Cobalt	8			9		
Lead	6	L 20	33	4	L 20	
Chromium	34			27		
Cadmium	0.7	L 4		1.0	L 4	

Data expressed on a ug or Bq/g dry weight basis.

¹ SRC baseline studies (average values).

² Environment Canada study (average values).

³ Eldor Mines annual reports.

There are only two parameters in which the data suggest something significant. The first is an anomalously high uranium value recorded in Hidden Bay of 580 ug/g in 1984. This value is significantly above the values that were recorded for Hidden Bay, including values of 64 ug/g in 1983 and 124 ug/g in 1985, and above what would be considered background for the area. Based upon past data, sediment uranium values for Hidden Bay may be expected to generally be below 100 ug/g, but show local values up to 150 ug/g. Values above this should be considered outliers and verified. The 1984 value of 580 ug/g requires confirmation. It may represent an area of high local sediment concentration, or may relate to sample contamination. The second sediment parameter of concern is zinc which appears to have dropped on the order of ten times during the period of the mine and mill operation. There does not appear to be any explanation for this, and it is suspected that the analyses carried out in 1972 (210 ug/g and 300 ug/g for Hidden and Pow Bays respectively) may have been in error as the average value of zinc in lake sediments for this area is on the order of 50 ug/g.

3.3 Fish Tissue Analyses

Fish in the Hidden Bay area have been analyzed intermittently from 1972 up until the present. The vast majority of the analytical results are listed as less than values, making it impossible to determine if there are any trends in the data. There is also a relatively high degree of uncertainty associated with the reported fish tissue analyses. On a recent large, uniformly homogenized sample from Hidden Bay, precision of the analyses, as suggested by variability within a given laboratory, was quite good being generally within 50%, but the accuracy of the analyses was much poorer with data on the same sample, in some cases differing by as much as 50 times, but in most cases agreeing within an order of magnitude. This is often found to be the case in analyses when the levels being analyzed are very close to or at the limits of analytical detection. Table 3.3 presents a summary of sediment, water and fish flesh data for radionuclides in Hidden Bay. These data have all been rounded to 'order of magnitude' numbers to show the general relationship which exists between these three environmental compartments. This summary, with data all expressed in the same units, shows quite clearly that the vast majority of radionuclides accumulate in the sediments, with levels in fish tissue being greater than in the water but less than in the sediments. The data also suggest that radionuclides do not bioconcentrate in the food chain. Since much of the data available for northern pike is 'less than' data, this suggestion is difficult to confirm. These rounded

TABLE 3.3: SUMMARY OF SEDIMENT WATER AND FISH RADIONUCLIDE LEVELS IN HIDDEN BAY (data expressed on a wet weight basis)

Radionuclide	Sediment*	Benthic Inverte- brates	Water	Fish	
				Bottom Feeder White Sucker	Predator Northern Pike
Uranium (nat) (mg/kg)	10	L 2	0.003	0.01 (NUTP) 0.02 (EC)	0.005
Thorium-230 (Bq/kg)	20	L 10	L 0.01	0.05 (NUTP) L 0.1	L 3.0
Radium-226 (Bq/kg)	20	L 10	0.007	L 0.1 (NUTP) L 0.03 (EC)	L 5.0 (Eldor)
Lead-210 (Bq/kg)	125	L 50	L 0.02	10 (NUTP) L 0.4 (EC)	L 5.0
Polonium-210 (Bq/kg)	125	L 50	L 0.02	1.0 (NUTP)	

* Sediment data assume an average moisture of 75%.

NUTP - National Uranium Tailings Program

EC - Environment Canada

ELDOR - Eldor Resources

values presented in Table 3.3 are judged to be as reasonable a reflection of the levels that have been present over the last five years or so as can be derived from the data. The differences between the NUTP and EC data are of the order that may be expected given the low levels of radionuclides being analyzed and the high degree of uncertainty that exists at these low levels.

In 1985, several specimens of northern pike, walleye, lake whitefish and lake trout from Hidden Bay were analyzed for a series of 17 trace elements plus four major elements. A review of these trace element data showed no unusual values that could not be explained nor values that would constitute a threat to public health. Some of the fish tissue showed what would normally be considered to be abnormally high aluminum values, but this was traced to the ashing of tissue in aluminum dishes prior to analysis. Mercury was not analyzed for in these samples.

4.0 SIGNIFICANCE OF MONITORING RESULTS

4.1 Effects on the Aquatic Environment

The discharges from the Rabbit Lake mining and milling operations could have conceivably affected the aquatic biota of Hidden Bay from three perspectives. These would include:

- o a physical effect from the discharge of large quantities of suspended solids;
- o a chemical effect associated with the discharge of dissolved chemicals; and
- o a radiological effect associated with the discharge of both particulate and soluble radionuclides.

Laboratory and field studies have shown that the effects of particulates on aquatic biota are usually very localized and even then only begin to be detectable when the discharges contain several thousands of parts per million of total suspended solids (TSS). A review of the available monitoring data and a visual inspection of the site have revealed no evidence of significant environmental effects associated with a physical sediment effect on the biology of Hidden Bay. The nature of the discharge creek which meanders through a boggy area and passes through Horseshoe Lake prior to discharge to Hidden Bay is such that any particulates of environmental significance which may escape the treatment settling basins would be settled out prior to reaching Hidden Bay.

An evaluation of chemical effects on biota is based upon both the dilution observed in the receiving water and the level of toxicity associated with the various parameters monitored. Bioaccumulation is considered based upon bioconcentration factors observed in Hidden Bay itself. This is preferable to literature values as it reflects actual local field conditions. An evaluation of radionuclide effects is handled in the same manner as for trace elements and other chemicals. Details of radiological dose calculations and its significance to aquatic biota are presented in Appendix I.

4.1.1 Dilution in Hidden Bay and Wollaston Lake

In order to evaluate the potential for chemical effects on the aquatic biota and people in the Hidden Bay area, it is necessary to know the water concentrations of various

chemical parameters. This is carried out from two perspectives. The first involves a review of measured concentrations of a chemical parameter in the receiving waters. These data are obtained by reference to a series of samples which have been from the open waters of Hidden Bay over the past several years. These are the data presented in the tables of Sections 2 and 3. This measured value is a combination of what is present naturally and the incremental concentration that has been added as a result of the mining and milling operations at Rabbit Lake. The second approach involves an evaluation of the discharge from the mining and milling operation and a calculation of the average incremental concentration in Hidden Bay based upon a dilution factor and subtracting background values. This simple dilution or mass balance approach will serve to overestimate the incremental concentration to a certain degree because of the fact that losses from the water column due to sedimentation are not accounted for.

In order to assess the incremental additions, an average dilution factor of 30% was assumed to apply to chemical parameters leaving the tailings treatment facility and entering Hidden Bay. This is an upper range value based upon observed dilution of conservative parameters such as chloride and sulphate, and takes into account additional flow from the Collins Bay pit and, as such, is an underestimate of dilution on a yearly average basis. Within Hidden Bay itself, there is a further dilution due to water entering the bay from both the portion of its watershed not occupied by the mine site and mixing with waters flowing in from the Umpherville River. The Geikie and Wheeler Rivers discharge into Nekweaga Bay at the south end of Wollaston Lake with a combined discharge of approximately $40 \text{ m}^3/\text{s}$. The discharge into Otter and Hidden Bays is on the order of $0.5 \text{ m}^3/\text{s}$ from local drainage, plus $5.5 \text{ m}^3/\text{s}$ from the Umpherville River. The input from Parks Lake to Hidden Bay has been estimated at an average annual flow of 4.6 L/s (Saskmont, 1982).

The average discharge from the mines wastewater treatment system is currently about 100 L/s (1,200 gpm). This flow combines with natural runoff from the local drainage basin resulting in an estimated annual average discharge to Hidden Bay of about 150 L/s. This flow is the combined flow from both the Rabbit Lake and Collins Bay operations. The inflow to Pow Bay from the Rabbit Lake drainage system was estimated at just under 20 L/s. Because this watershed presently receives only cooling water and waste rock runoff discharge, the effect from this source on Wollaston Lake is secondary to that from the effluent stream entering Hidden Bay. The average discharge from the tailings treatment facility prior to the development of the pit in Collins Bay is estimated at about 60 L/s.

The Hidden Bay, Otter Bay, Pow Bay area is thus flushed by an average long-term flow on the order of $6 \text{ m}^3/\text{s}$ providing an overall dilution on the order of something greater than 50 times. The dilution prior to 1985 was about twice this amount at 100:1. The minimum dilution in the main body of Wollaston Lake where mixing with another $40 \text{ m}^3/\text{s}$ of water occurs would thus be on the order of another six to seven times. These values are important in the context of setting up monitoring programs and trying to interpret monitoring data that are designed to evaluate incremental additions of chemicals and radionuclides from the mining operation. For all of the parameters investigated as part of this study, including both the radionuclides and trace elements, the analytical data were not sensitive enough to separate out 'background levels' from incremental additions from the mining and milling operations for all but a couple of parameters.

4.1.2 Radiation Effects on Aquatic Environment

Radiation doses and chemical effects on fish and other aquatic animals were calculated for those animals living in Hidden Bay. These effects were calculated based upon the levels that were actually observed, through monitoring programs, in the sediment, water and animals themselves. Details of these calculations are presented in Appendix 1.

The highest radiation dose was calculated for those animals which live directly in the sediments on the bottom of Hidden Bay. They receive the highest radiation doses because they are in full-time, direct contact with the sediments which have the highest radionuclide levels of any environmental compartment. The highest radiation dose calculated to these invertebrates from all radionuclides and all environmental pathways was less than 1 uGy/h . The lowest radiation dose at which any type of detrimental effect has been noticed under laboratory conditions is on the order of 100 uGy/h . Accordingly, the most exposed biota have, at present, a safety factor in excess of 100 times before any observable effects may be expected to occur.

It should be noted that this calculated radiation dose to aquatic animals is based upon monitored levels and is thus the sum of both background levels and an incremental level that has been added by the mining operation. The actual radiation dose that the animals receive that is due to the mining and milling operation discharges would thus be a small fraction of the 1 uGy/h mentioned previously. The fish population in Hidden Bay is not in direct contact with the sediment, but rather the water which has a much lower

radionuclide level. Accordingly, the dose rate to fish is closer to 2 nGy/h or about 500 times less than for the animals living on the bottom. Thus, the radiation risk to the fish population of Hidden Bay and Wollaston Lake from the Rabbit Lake mining operation during the past decade must be considered insignificant.

4.1.3 Chemical Effects on Aquatic Environment

The levels of monitored chemical parameters in both the effluent discharges to Hidden Bay and in the waters of Hidden Bay were compared with both surface water quality objectives and with levels at which effects on aquatic biota have been observed. Table 3.1 presents the long-term mean and median values for Hidden Bay and other nearby water bodies which were used for assessment purposes in this study. A review of these data, along with that presented in Section 2.0, shows that the long-term median water quality that is found adjacent to the Rabbit Lake facility presents no long-term or chronic risk to the aquatic biota of Hidden Bay or adjacent waters that have been monitored. A review of the high values that were observed during monitoring has also shown that acutely toxic short-term exposure was not present in Hidden Bay or adjacent waters during the period investigated.

The one exception to this general statement is for ammonia. In the late 1970's, investigations carried out by Environment Canada have shown that a combination of total ammonia and pH conditions may have resulted in conditions in portions of Hidden Bay adjacent to the effluent discharge which may have been toxic to fish. There were no reports of fish kills, but toxicity testing carried out by Environment Canada and literature studies suggest a transient negative impact may have occurred. Present plans call for the discontinuation of ammonia use in the process with the development of the Collins Bay ore zone. No further problems with ammonia are anticipated because of this process change.

4.2 Effects on Local Human Populations

In determining the potential effect of chemical and radionuclide discharges from the Rabbit Lake facility on local human populations, a reference group was assumed to exist. This group would be expected to have the highest exposure to both chemicals and radionuclides released from the Rabbit Lake facility. This reference group is assumed to

get all of its drinking water from Hidden Bay and consume 20 kg of fish each year that are caught in Hidden Bay. In this way, members of the reference group are assumed to be exposed to trace elements and radionuclides both through the water they drink and the fish that they eat.

4.2.1 Assessment of Chemical Effects

A review of the analytical data summaries and data trends in Sections 2.0 and 3.0 of this report has shown that, after discrepancies in much of the raw data have been accounted for and corrected, all of the water quality parameters that are routinely monitored for in Hidden Bay meet drinking water standards. This would mean that the waters of Hidden Bay at the mid-Bay monitoring point are acceptable for year-round human consumption.

At some times and at some locations around the Rabbit Lake facility, the monitoring data have shown marked fluctuations that do not appear to be directly related to discharges from the facility. In the majority of cases, these fluctuations have been traced to sample contamination and/or analytical problems (Filion, 1985). In other cases, the reported detection limits for particular analysis have been greater than drinking water standards. These high reported detection limits have had the effect of causing the reported average water concentration in Hidden Bay to appear higher than in fact it is suspected of having been.

In other instances, such as for uranium, fluctuations in effluent chemistry, were expected to result in fluctuations in uranium levels in Hidden Bay. This, in fact, was observed to occur and, although average levels did not exceed drinking water standards, it is possible that levels may have exceeded drinking water standards for short periods of time in Hidden Bay between where the effluent stream enters and where Hidden Bay opens to Wollaston Lake. These suspected short-term excursions above drinking water standards do not pose a significant public health risk, but emphasize the need for accurate monitoring.

The dilution of effluent in Hidden Bay which is presently on the order of 50:1 on a long-term average and at least 10:1 during short-term dry periods would suggest that, in order to ensure that water of drinking water quality is maintained in Hidden Bay at all times, effluent discharge levels should not on a long-term basis exceed a value of ten times the

drinking water standard. For the chemical parameters of concern, this would ensure, with a margin of safety, that Hidden Bay waters would remain safe for unrestricted human use and not pose any risk to natural populations.

4.2.2 Assessment of Radiological Risk

Just as in the case of assessment of chemical effects, it was necessary to assume that there may be some group of individuals who would obtain all of their drinking water from Hidden Bay and eat 20 kg of fish a year from the bay. The highest concentrations of radionuclides appear from the data collected to date to be found in the bottom-feeding white suckers. This is not unexpected inasmuch as the sediments are the environmental compartment with the highest radionuclide levels and the radionuclides associated with the uranium decay series have not been observed to bioconcentration in food chains.

Table 4.1 presents the best estimate data for both water and fish radionuclide concentrations for the waters of Hidden Bay, along with a calculated non-stochastic radiation dose which is calculated based upon consumption of both water and fish from the bay. In cases where the measured values were less than the analytical detection limit, the value used for dose calculation purposes was the detection limit. The result of this is that the resultant calculated radiation dose is an overestimate of the actual dose and consequently the 'safety factor' or the amount by which someone drinking all of their water and eating fish from Hidden Bay is below the maximum permissible dose for members of the general public is underestimated. Also presented is a total stochastic radiation dose to the whole body. This value shows a safety factor of about 25 times and incorporates the radiation dose received from all of the radionuclides listed. This suggests that, in order for someone to exceed the maximum permissible radiation dose for members of the general public, they would have to consume over 15,000 L of water and 500 kg of fish per year from Hidden Bay having the maximum levels of radionuclides which are presently found in Hidden Bay.

Based upon these data, there does not appear to be any significant potential for a significant radiation health risk arising from drinking waters and eating fish from Hidden Bay. It is also reasonable to conclude that, because it is assumed that the values found in Hidden Bay are probably the highest due to discharge of radionuclides from the Rabbit Lake facility of any water body in Wollaton Lake, the water and fish of Wollaston Lake do not comprise a significant health hazard to anyone consuming them.

TABLE 4.1: ASSESSMENT OF RADIOLOGICAL RISK FROM HIDDEN BAY

Radionuclide	Water Concentration (Bq/kg)	Fish Concentration (Bq/kg)	Calculated Dose	Safety Factor
Uranium	0.075	0.5	55×10^{-6} Sv (NS)	900
Thorium-230	L 0.01	0.05	3.6×10^{-3} Sv (NS)	14
Radium-226	0.007	0.03	32.6×10^{-6} Sv (NS)	1,500
Lead-210	L 0.02	2.0	1.1×10^{-3} Sv (NS)	45
Polonium	L 0.02	1.0	1.4×10^{-4} Sv (NS)	360
TOTAL			2.1×10^{-4} Sv (S)	25

5.0 CONCLUSIONS

A review of the environmental monitoring data collected for sediments, water and fish in the vicinity of the Eldor Resources Rabbit Lake uranium mining and milling operation over the last decade allows several conclusions to be drawn. The following conclusions are based primarily on data derived from the Hidden Bay area and substantiated by cross-reference to both the discharges to Hidden Bay from both the Umpherville River and the effluent stream where it discharges to Hidden Bay. Hidden Bay was judged to be the waterbody 'most at risk' because it receives the highest percentage of the discharges from the Rabbit Lake facility and any deleterious effects may be expected to occur in Hidden Bay prior to appearing elsewhere in Wollaston Lake.

As an overall conclusion, it can be stated that, on the basis of the available data, the operation of the Rabbit Lake uranium mining and milling operation has had no significant nor discernable effect on the aquatic ecology, fishery or any other use of the waters of Hidden Bay or Wollaston Lake.

The following more specific conclusions relate to specific areas addressed in the report.

- 5.1 Any changes which may have occurred in the sediment chemistry of Hidden Bay are small enough that they are masked by either analytical uncertainty or spatial variability, and do not constitute a significant threat to either the natural or human environment.
- 5.2 A review of the water chemistry data for both radionuclides and trace elements has shown that the majority of the values obtained are within an order of magnitude of the detection limit and are subject to large uncertainties in analytical accuracy. These large analytical uncertainties, coupled with changes in analytical procedures and techniques throughout the monitoring period, makes it impossible to discern any trends in much of the data. The majority of trace elements, taking into account the magnitude of uncertainty associated with the data, are at levels where there is no threat to either the natural environment nor public health. The levels at which copper can cause chronic effects on aquatic populations are within the range of analytical uncertainty found in the data and no definitive conclusion can be drawn about the levels of copper found in the Umpherville River, the effluent discharge to Hidden Bay or Hidden Bay itself.

- 5.3 Levels of ammonia in the effluent discharge to Hidden Bay and in certain portions of Hidden Bay over the monitoring period have exceeded levels which may be considered deleterious to fish populations. No conclusive evidence of fish being affected has been found in a review of the data and, since fish can sense ammonia, they may simply have swum away and avoided the high levels. Any effects of ammonia would have been limited in both spatial and temporal effects and the long-term effect on the fishery in Hidden Bay would be insignificant.
- 5.4 A review of radionuclide levels in all major aquatic ecosystem components, sediment, water and fish, even when the highest probable values are considered, suggests that levels are well below where there would be any significant effect on the fish or any other natural populations.
- 5.5 A review of the most probable recent levels of radionuclides in both water and fish from Hidden Bay which people may reasonably be expected to consume suggests that no individual, even if obtaining all of his drinking water and fish from Hidden Bay, would be exposed to an unsafe level of radiation. Much of the older radionuclide data that have been collected over the last ten years in the Hidden Bay area has not been accurate enough to allow this statement to be made for the entire period of operation of the mine, although there is no evidence to suggest any unsafe levels have occurred in the past.
- 5.6 A review of sample collection, sample handling and analytical methodology and technique is required to ensure that data obtained from environmental monitoring samples is of sufficient precision to allow trends to be spotted and of sufficient accuracy to allow evaluation of potential environmental effects.

6.0 RECOMMENDATIONS

The review of environmental monitoring data that have been collected around the Rabbit Lake facility over the last ten years suggests that there are several areas in which improvements can be made. These generally fall into the area of sample collection and analysis and the area of data interpretation.

- 6.1 Future monitoring data be collected and analyzed in accordance with a specified quality assurance and control program that reflects the use for which the data are being collected. The data accuracy should be such that it is sufficient to discriminate clearly whether or not a potential threat to the natural environment or human health exists. Table 6.1 presents a summary of what should be routine operating detection limits in a laboratory which employs a good quality control/quality assurance program and has an adequate sample for analysis. Alongside this value is a recommended lower limit which is based upon a value of 10% of the level at which concern may be raised for either a natural fish population or human health. If good sampling and analytical control is maintained at this 10% level, potential concerns can be easily detected and remedial measures implemented.
- 6.2 All monitoring data that are collected in future programs should be presented in a standardized format such that environmental evaluations and trends can be readily analyzed. It is recommended that data be presented on a wet or fresh basis.
- 6.3 Monitoring programs should be continued in the area which employ proper QA/QC procedures and, if 'unusual or unexpected' data appear, it should be immediately verified and not allowed to be put into a database or report as a piece of questionable data the significance of which may be soon lost.
- 6.4 Incorrect statistical data such as zero values and extremely high 'less than' values which are at present in the Esquadat database should be edited out and statistical values recalculated where appropriate.

TABLE 6.1: COMPARISON OF ROUTINE ANALYTICAL DETECTION LIMITS WITH LIMITS REQUIRED FOR ENVIRONMENTAL SAFETY ASSESSMENT IN URANIUM MINING AND MILLING
(Detection limits are expressed on a fresh or wet weight basis)

Parameter	Sediment ¹	Environmental Compartment Water ²		Fish ³	
	Routine Analytical Detection Limits*	Routine Analytical Detection Limit Available	Required Detection Limit (10% of max. permissible)	Routine Analytical Detection Limit Available	Required Lower Limit Wet Weight (10% of max. permissible)
Radionuclides					
Thorium-230	5 Bq/kg	0.005 Bq/L	0.38 Bq/L	0.5 Bq/kg	1.0 Bq/kg
Radium-226	5 Bq/kg	0.005 Bq/L	1.5 Bq/L	0.1 Bq/kg	77.5 Bq/kg
Lead-210	100 Bq/kg	0.1 Bq/L	0.2 Bq/L	2 Bq/kg	15.5 Bq/kg
Polonium-210	5 Bq/kg	0.005 Bq/L	1.0 Bq/L	1 Bq/kg	47.0 Bq/kg
Chemical					
Uranium	500 ug/kg	0.5 ug/L	2 ug/L	10 ug/kg	40 ug/kg
Arsenic	50 ug/kg	0.2 ug/L	5 ug/L	10 ug/kg	100 ug/kg
Copper	500 ug/kg	2 ug/L	1 ug/L	50 ug/kg	1,000 ug/kg
Lead	1,000 ug/kg	5 ug/L	5 ug/L	100 ug/kg	100 ug/kg
Zinc	500 ug/kg	2 ug/L	5 ug/L	50 ug/kg	1,000 ug/kg
Selenium	50 ug/kg	0.2 ug/L	5 ug/L	10 ug/kg	100 ug/kg
Vanadium	500 ug/kg	5 ug/L	1 ug/L	50 ug/kg	20 ug/kg
Nickel	500 ug/kg	5 ug/L	5 ug/L	50 ug/kg	1,000 ug/kg

* Existing limits are adequate for all parameters.

ug/kg = parts per billion.

¹ Assumes a 1 g sample size for radionuclides.

² Assumes a 1 L sample size for radionuclides.

³ Assumes a 100 g sample size for radionuclides.

- 6.5 Any changes in process chemistry or ore type that may occur with the development of the Collins Bay deposit should be evaluated as to the manner in which it may affect the parameters being monitored for in the environmental monitoring program.

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APPENDIX I

DOSE RATES TO AQUATIC BIOTA

A1.0 DOSE RATES TO AQUATIC BIOTA

Aquatic biota are important in their role as food for fish and in the cycling of organic matter and trace elements. Dose rates to aquatic biota are calculated in order to determine if levels of radionuclides in the aquatic environment pose any threat to the aquatic populations near the Rabbit Lake operations. An extensive literature on dose and dose rate effects in aquatic organisms has been reviewed in NRCC 19250 (1983), IAEA TR-190 (1979), Blaylock and Trabalka (1978), IAEA TR-172 (1976), Andrushaytis (1973), Chipman (1972), Il'yenko (1969) and Polikarpov (1966). Dose rate calculations are based on IAEA TR-172 and Woodhead (1970). All dose rates to aquatic biota are expressed in Grays/unit time. This is because there are no appropriate quality factors for radiation that are applicable to species other than man.

A1.1 Dose Rates from Incorporated Radionuclides

Internal dose rates DR(Gy/hr) from alpha (α), beta (β) and gamma (γ) radiation are calculated on the assumption of uniform radionuclide distribution through the organism:

$$DR(\alpha) = N_{\alpha} (5.8 \times 10^{-4}) E C$$

$$DR(\beta) = N_{\beta} (5.8 \times 10^{-4}) E C$$

$$DR(\gamma) = 2.7 \times 10^{-7} \Gamma p \bar{g} C$$

N_{α} and N_{β} are constants equal to unity for all large organisms (crayfish, clams, fish) and are an expression of the amount of the energy released in a given decay that is absorbed in the tissue of the animal being considered. For plankton, $N_{\alpha} = 0.3$ and $N_{\beta} = 0.007$.

E_{α} and E_{β} are radionuclide emission energies given in Tables A1 and A2.

Γ is the gamma ray constant for each radionuclide (Table A2).

p is organism density (l/cm^3) and assumed to be 1.

$\bar{g}$ is a mean geometric factor representing the size and shape of the organism.

TABLE A1: PRINCIPAL RADIATIONS EMITTED BY THE URANIUM-238 SERIES

Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities		
			α	β	γ
^{238}U	Uranium I	$4.51 \cdot 10^9$ y	4.15 (25%) 4.20 (75%)	-	-
^{234}Th	Uranium I ₁	24.1 d	-	0.10 (21%) 0.19 (79%)	0.06 (3.5%) 0.09 (4%)
$^{234\text{m}}\text{Pa}$	Uranium I ₂	1.17 m	-	2.29 (98%)	0.77 (0.3%) 1.00 (0.6%)
99.87% ^{234}Pa 0.13%	Uranium I ₂	6.75 h	-	0.53 (66%) 1.13 (13%)	0.10 (50%) 0.70 (24%) 0.90 (70%)
^{234}U	Uranium II	$2.47 \cdot 10^5$ y	4.72 (28%) 4.77 (72%)	-	0.05 (0.2%)
^{230}Th	Ionium	$8.0 \cdot 10^4$ y	4.62 (24%) 4.68 (76%)	-	0.07 (0.6%) 0.14 (0.07%)
^{226}Ra	Radium	1620 y	4.60 (6%) 4.78 (95%)	-	0.19 (4%)
^{222}Rn	Emanation Radon (Rn)	3.823 d	5.49 (100%)	-	0.51 (0.07%)
^{218}Po	Radium A	3.05 m	6.00 (~100%)	0.33 (~0.019%)	-
99.98% ^{214}Pb 0.02%	Radium B	26.8 m	-	0.65 (50%) 0.71 (40%) 0.98 (6%)	0.30 (19%) 0.35 (36%)
^{218}At	Astatine	~2 s	6.65 (6%) 6.70 (94%)	? (~0.1%)	-
^{214}Bi	Radium C	19.7 m	5.45 (0.012%) 5.51 (0.008%)	1.0 (23%) 1.51 (40%) 3.26 (19%)	0.61 (47%) 1.12 (17%) 1.76 (17%)
99.98% ^{214}Po 0.02%	Radium C'	164 μs	7.69 (100%)	-	0.80 (0.014%)
^{214}Tl	Radium C"	1.3 m	-	1.3 (25%) 1.9 (56%) 2.3 (19%)	0.30 (80%) 0.80 (100%) 1.31 (21%)
^{210}Pb	Radium D	21 y	3.72 ($2 \times 10^{-6}\%$)	0.02 (85%) 0.06 (15%)	0.05 (4%)
^{210}Bi	Radium E	5.01 d	4.65 ($7 \times 10^{-5}\%$) 4.69 ($5 \times 10^{-5}\%$)	1.16 (~100%)	-
100% ^{210}Po 0.00013%	Radium F	138.4 d	5.31 (100%)	-	0.80 (0.0011%)
^{206}Tl	Radium E"	4.19 m	-	1.57 (100%)	-
^{206}Pb	Radium G	Stable	-	-	-

TABLE A2: FACTORS EMPLOYED IN DETERMINING DOSES TO AQUATIC BIOTA

Radionuclide	$E\alpha$ (MeV)	$E\beta$ (MeV)	γ (rad/hr per mCi/cm ²)
Uranium ¹	9	0.87	0.074
Th-230	4.7	-	-
Ra-226	4.8	-	0.03
Rn-222 (+ short-lived daughters)	24.0	0.75	5.1
Pb-210 ²	5.3	0.41	0.02
Po-210	5.3	-	-

¹ Includes U-238, Th-234, Pa-234, U-234

² Includes Bi-210, Po-210

C is the radionuclide concentration in the tissue of the organism (Bq/kg).

These values are measured values where available and, where no measurements have been made, estimated values were used based upon levels in water and sediment and the application of appropriate bioconcentration factors.

The invertebrate model used is that for larger invertebrates, such as crayfish ($\bar{g} = 10.6$) and fingernail clams ($\bar{g} = 4.7$) and, as such, provides a slight overestimate of dose for smaller invertebrates such as worms and insect larvae.

Fish are represented as cylinders 10 cm in radius and 50 cm long ($\bar{g} = 41$). The tissue concentrations in this range of invertebrates is assumed to be for all groups at the less than level shown in Table 3.2 and is, therefore, a upper estimate of radiation dose. The dose rates calculated for aquatic biota from incorporated radionuclides in the uranium decay series are shown in Table A3 for unit concentrations. The calculated dose is directly proportional to the radionuclide concentration.

A1.2 Dose Rates from Water

External dose rates (uGy/hr) from alpha (α) irradiation by radionuclides in the water are calculated as in Section A1.1 with $N\alpha = 0$ for both invertebrates and fish. Consequently, the α dose in Table A4 is zero.

The beta (β) component of the external water dose rate for both invertebrates and fish is also very low, and is essentially zero in Table A4.

The gamma (γ) component of the external water dose rate for any organism is given by:

$$DR(\gamma) = (2.7 \times 10^{-7}) E_{\gamma} C$$

where E_{γ} is the radionuclide emission energy (Table A1).

External dose rates from water are calculated in Table A4 assuming a water concentration of 1 Bq/L. Dose rates to biota within Hidden Bay are given in Table A6 as calculated from these dose conversion factors and the environmental compartment data in Table 3.3.

TABLE A3: DOSE RATES TO BIOTA FROM INCORPORATED RADIONUCLIDES
(uGy/hr per Bq/g)

Radionuclide	Plankton	Crayfish	Clams	Fish
Uranium ¹				
Alpha	1.6	0.5E+1	0.5E+1	0.5E+1
Beta	0.4E-2	0.5	0.5	0.5
Gamma	0.5E-6	2.1E-4	0.9E-4	0.8E-3
Th-230				
Alpha	0.8	0.3E+1	0.3E+1	0.3E+1
Ra-226				
Alpha	0.8	0.3E+1	0.3E+1	0.3E+1
Gamma	2.0E-7	0.9E-4	0.4E-4	0.3E-3
Pb-210 (+ Daughters)				
Alpha	0.9	0.3E+1	0.3E+1	0.3E+1
Beta	0.5E-2	2.6E-1	2.6E-1	2.6E-1
Gamma	1.3E-7	0.6E-4	2.6E-5	2.2E-4
Po-210				
Alpha	0.9	0.3E+1	0.3E+1	0.3E+1

¹ Includes U-238, Th-234, Pa-234, U-234

TABLE A4: DOSE RATES TO BIOTA FROM WATER (uGy/hr per Bq/L)

Radionuclide	Plankton	Crayfish	Clams	Fish
Uranium ¹				
Alpha	0.4E-2	-	-	-
Beta	0.5E-3	-	-	-
Gamma	2.1E-6	2.1E-6	2.1E-6	2.1E-6
Th-230				
Alpha	1.9E-3	-	-	-
Ra-226				
Alpha	1.9E-3	-	-	-
Gamma	0.3E-5	0.3E-5	0.3E-5	0.3E-5
Rn-222 (+ Short-Lived Daughters)				
Alpha	0.8E-2	-	-	-
Beta	0.4E-3	-	-	-
Gamma	0.5E-3	0.5E-3	0.5E-3	0.5E-3
Pb-210 (+ Daughters)				
Alpha	2.1E-3	-	-	-
Beta	2.3E-4	-	-	-
Gamma	1.1E-3	1.1E-3	1.1E-3	1.1E-3
Po-210				
Alpha	2.1E-3			

¹ Includes U-238, Th-234, Pa-234, U-234

A1.3 Dose Rates from Contaminated Sediments

The gamma dose rate in air (urad/hr) from soil uranium in equilibrium with its daughters is given by Gustafson and Brar (1963) as:

$$D_u = 0.779 \times 10^4 S_u$$

where S_u is uranium concentration (g / g). The dose rate D_u is essentially constant to about 1 m above ground level (Beck, 1972). D_u is 0.62 Gy/hr per Bq/g.

The dose rate from gamma radiation is approximately proportional to the total emitted gamma ray energy (Rockwell, 1956). Consequently, the dose rate from particular radionuclides or groups of radionuclides may be calculated from the fraction of total gamma energy which they contribute:

$$U^{238} - U^{234} \quad DR(\gamma) = \frac{0.0315}{0.9589} (0.62) = 0.020$$

$$Ra^{226} \quad DR(\gamma) = \frac{0.0057}{0.9589} (0.62) = 0.0037$$

Gamma dose rates from sediments are listed in Table A5.

Beta dose rate calculations were based on a simplified sediment model of radioactivity concentrated in four infinite planes 1.25, 3.75, 6.25 and 8.75 mm below the surface. The sediment was assumed to have a bulk density of 1.5 g/cm³. At 1 Bq, sediment contamination in each plane is 0.38 Bq.

Cross (1967) gives the dose rate in water above an infinite plane for a variety of beta-emitting radionuclides. These can be used as reference nuclides to derive dose rates for uranium series nuclides with similar beta energies (Table A6).

The reference nuclide dose rate is multiplied by the beta percentage intensity of the uranium series nuclide and the contamination level in the sediment plane. The resulting beta dose rates are shown in Table A5 for sediment concentrations of 1 Bq/g. Actual

TABLE A5: DOSE RATES TO BIOTA IN AND ON SEDIMENTS (uGy/hr per Bq/g)

Radionuclides	Beta	Gamma
Uranium ¹	0.3	2.0E-2
Ra-226	-	3.7E-3
Short-Lived Rn Daughters	0.21	0.6
Long-Lived Rn Daughters	0.04	-

¹ Includes U-238, Th-234, Pa-234, U-234

TABLE A6: PARAMETERS FOR CALCULATING DOSE RATES FROM SEDIMENT

Uranium				
Series Nuclide		Reference Nuclide		
Symbol	$E_{\beta \text{ max}}$ (Mev)	Symbol	$E_{\beta \text{ max}}$ (Mev)	Beta Dose Rate (Gy/hr per Bq/cm ²)
Pa ^m -234	2.3	Y-90	2.3	0.9
Pb-214	0.68	Cs-134	0.66	0.8E-2
Bi-214	1.0	Bi-210	1.2	1.2E-1
Bi-214	1.5	Y-91	1.5	0.5
Bi-214	3.3	K-42	3.5	1.5
Tl-210	1.9	Ga-68	1.9	0.6
Bi-210	1.2	Bi-210	1.2	1.2E-1

dose rates from sediments in Hidden Bay based upon the levels shown in Table 3.3 is presented in Table A7.

TABLE A7: RADIATION DOSE RATES TO AQUATIC BIOTA IN HIDDEN BAY

Exposure Pathway	Environment Canada Incremental Estimates for Biota in Otter Bay	Dose Rate (mGy/a) Based Upon Monitored Data in Table 3.2
Dose for Radioactivity in the Water and in the Tissue of the Organism:		
Invertebrates (clams, crayfish, insects)	0.138	5.65 (0.645 uGy/h)
Fish (suckers)	0.015	0.32 (0.037 uGy/h)
External Dose from Sediments to Benthic Invertebrates:		
Beta	0.711	1.0 (0.115 uGy/h)
Gamma	0.04	0.657 (0.075 uGy/h)

Lowest dose at which effects have been observed on invertebrates under laboratory conditions is 100 uGy/h. Ecological effects would not be expected until levels several hundreds to thousands of times higher than this value.

PHOTOGRAPHIC APPENDIX



Photo 1: Aerial view of the Rabbit Lake open pit showing the waste rock pile to the upper right of the open pit and the mill complex to the left of the open pit. During the 1970's, some runoff water from the mine and mill area ran down by surface flow into the Link Lakes shown in the lower centre of the picture. Water quality was monitored periodically at the control structure at the outlet of Link Lakes. Outflow then flowed through a slow flowing marshy area into Pow Bay. A review of water quality data from Link Lakes and in Pow Bay suggests no adverse environmental effects occurred from releases in this area.



Photo 2: After surface runoff to the Link Lakes was stopped, all process flow and surface runoff which may have become contaminated was put through the main tailings area shown in the lower centre of the photo. Flow from the tailings was then treated and settling occurred in the decant ponds shown at the top of the tailings area. The treated decant then flowed through a poorly defined channel to Hidden Bay shown in the upper centre of the picture.



Photo 3: The treated effluent from the tailings treatment system after flowing through a meandering channel discharges into Hidden Bay in the marshy area at the centre left of Photo 6. Water quality data from this area over the last ten years suggest that, at certain times, the levels of ammonia may have been at levels in the marshy delta area which would be detrimental to fish and other aquatic species. With the cessation of ammonia use in mid-1986, ammonia is not expected to pose a concern in the future.

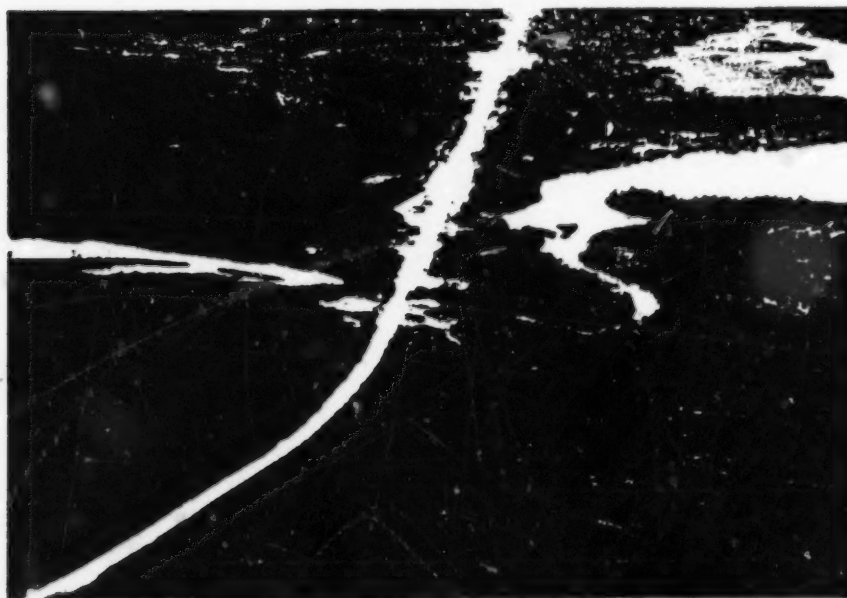


Photo 4: Control water samples from the Umpherville River were collected from just above where Highway 105 crosses the Umpherville River. Photo 4 shows this location where there have been small water quality fluctuations over the last ten years, but nothing of environmental significance.



Photo 5: The Umpherville River after it crosses Highway 105 discharges into Hidden Bay just above the centre and to the right in this picture. The flow then mixes with the waters of Hidden Bay and the effluent from the Rabbit Lake facility before discharging into Wollaston Lake.



Photo 6: Hidden Bay which presently receives all of the treated process and runoff water from the Rabbit Lake mine and mill complex is shown in this picture. The Umpherville River enters the Bay in the marshy lower left-hand corner of the Bay, and the treated process and runoff water enters further out into the Bay at the top of the light brown marshy area. The water quality samples for Hidden Bay were collected in the middle section of Hidden Bay after the effluent flow and the flow from the Umpherville River have had a chance to mix. Water quality data from this location over the last ten years suggest that no significant effect on the natural environment has occurred in this area and, by inference, there has been no significant effect on water quality in Wollaston Lake.



Photo 7: Photo 7 shows the new Collins Bay development. The recently constructed open pit that is dyked off from Collins Bay is shown to the centre right of the picture. The large cleared area in the lower centre of the photo has been cleared and prepared as an ore storage area. The pumping station to pump all pit and runoff water for treatment at the main treatment site prior to discharge to Hidden Bay is shown at the centre left of the picture.

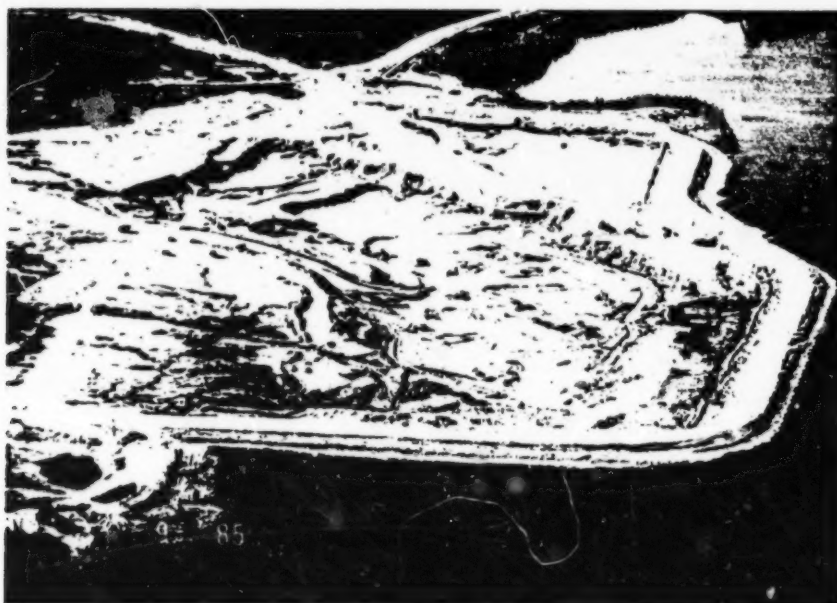


Photo 8: Photo 8 is a close-up of the open pit development in Collins Bay. The level of the Collins Bay pit is below the level of Collins Bay and all flows from the development are from the Bay to the pit. Consequently, no discharges to Collins Bay are planned and no environmental effects are anticipated other than on that section of the bay actually excavated and covered by the retaining dyke.